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Effects of Ancient Stream Channel Deposits on Mine Roof Stability: A Case Study

By David K. Ingram and Frank E. Chase



UNITED STATES DEPARTMENT OF THE INTERIOR



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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	m	meter
ft	foot	pct	percent
ft ²	square foot	psi	pound (force) per square inch
in	inch		

EFFECTS OF ANCIENT STREAM CHANNEL DEPOSITS ON MINE ROOF STABILITY: A CASE STUDY

By David K. Ingram¹ and Frank E. Chase¹

ABSTRACT

The Bureau of Mines conducted underground mapping and rock strength tests to describe and analyze mine roof conditions surrounding ancient stream channel deposits (paleochannels) in the Pittsburgh Coalbed in southwestern Pennsylvania. Paleochannels in the study mine consist of sandstone and/or siltstone and affect the Pittsburgh Coalbed through erosion and/or differential compaction. Differentially compacted sediments within and adjacent to channel deposits caused slip planes, faults, clay-dike faults, clastic dikes (clay veins), coalbed rolls, and slumped structures. Paleochannels can be predicted by recognizing these features and associated sediments, which allows for modification of long- and short-term mine planning and development.

Mine entries located beneath the paleochannel deposits exhibit less stable roof conditions than entries with normal (nonchannel) roof. Paleochannel deposits comprise only one-fourth of the mapped study area; however, they contain one-half of the hazardous roof. This study determined that rock strength evaluations, including rock quality designation (RQD), unconfined uniaxial compressive strength testing, and point-load testing, must be accompanied by underground observations. Suggested remedial support techniques include angled and/or longer tensioned bolts, steel mats or crossbars, steel sets or cribbing, and roof trusses.

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INTRODUCTION

Ancient stream channel deposits (paleochannels) are commonly preserved in and above coalbeds. Paleochannels often cause an absence or thinning of the coalbed; therefore, mine personnel sometimes refer to them as faults, rolls, wants, washouts, or stone dikes. Paleochannels reduce recoverable reserve estimates, complicate long-term mine projections, and disrupt the routine mining cycle. Differential compaction of sediments in proximity to paleochannels may cause slip planes, faults, clastic dikes, and coalbed and roof rolls. Roof spalling adjacent to paleochannels is sometimes severe during and after mining. For

these reasons, paleochannels are considered roof control safety hazards (1).²

The primary objectives of this study were (1) to identify the geologic characteristics of paleochannels and how they influence roof stability, (2) to determine if these characteristics can be used to predict paleochannel trends in advance of mining, and (3) to suggest remedial roof support and mining methods to minimize roof control problems. This information is beneficial to operators in developing and modifying long- and short-term mine plans. Some characteristics discussed here may be applied to other coalbeds and other localities.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Gateway Coal Co. in Prosperity, PA, for allowing the Bureau to have access to

their mine, mine facilities, and engineering data during the course of this research endeavor.

GEOLOGIC SETTING

Gateway Mine is located in Greene County, PA, approximately 35 miles south-west of Pittsburgh (fig. 1). The mine operates in the Pittsburgh Coalbed. The property is situated in the Dunkard Basin, which contains gently folded strata (dips generally less than 1°) and lies within the Appalachian physiographic province. Gateway Mine is situated along the flanks of the Belle Vernon and Amity anticlines and Waynesburg syncline (fig. 2) (2). Average overburden thickness is approximately 800 ft (243 m) throughout the study area.

Stratigraphically, the Pittsburgh Coalbed is at the base of the Pittsburgh Formation in the Monongahela Group (fig.

3). The Pittsburgh Formation has five members (3). This study is primarily concerned with the lowest member, called the Lower Member. This member is identified by its basal bed, the Pittsburgh Coalbed, which was deposited in a swamp environment. The Pittsburgh Coalbed is overlain by either shales and rider coals or the Pittsburgh Sandstone, the thickest and most extensive sandstone in the Monongahela Group. This investigation focuses on the Pittsburgh Sandstone because it is the lithified remnant of the ancient channel system responsible for the discontinuities encountered at the Gateway Mine.

PALEOCHANNEL FORMATION

Detailed underground mapping revealed that the Pittsburgh Coalbed in the study area is overlain by either the Pittsburgh Sandstone (paleochannel deposits) or the rider coal interval (fig. 4). Paleochannel deposits are composed of sandstone, siltstone, and/or interbedded sandstones and siltstones. Sandstone deposits range

from relatively clean to highly carbonaceous and, in some cases, may be poorly cemented and friable. Siltstone deposits are dark gray and high in organic

²Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

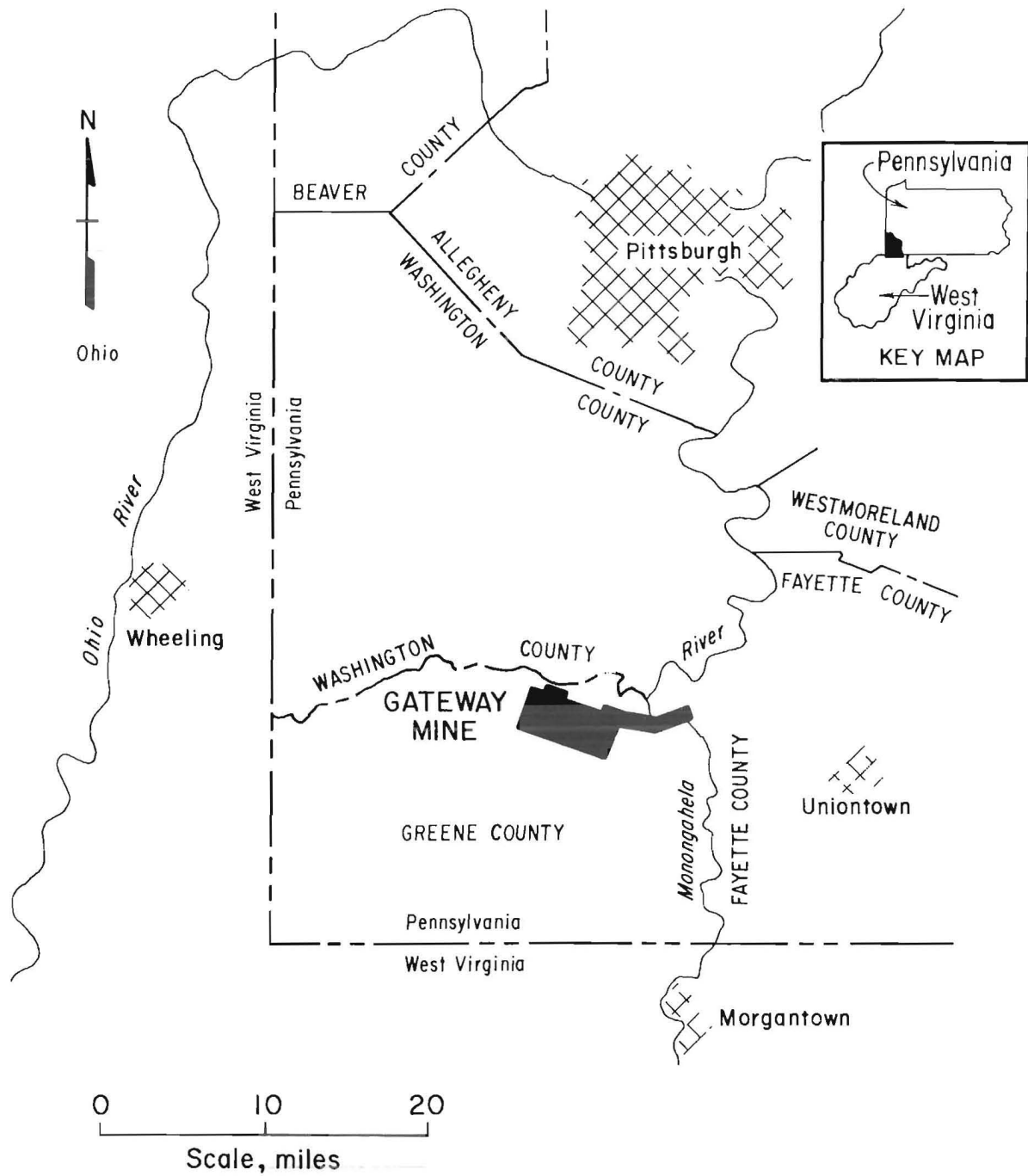


FIGURE 1.—Location of Gateway Mine in southwestern Pennsylvania.

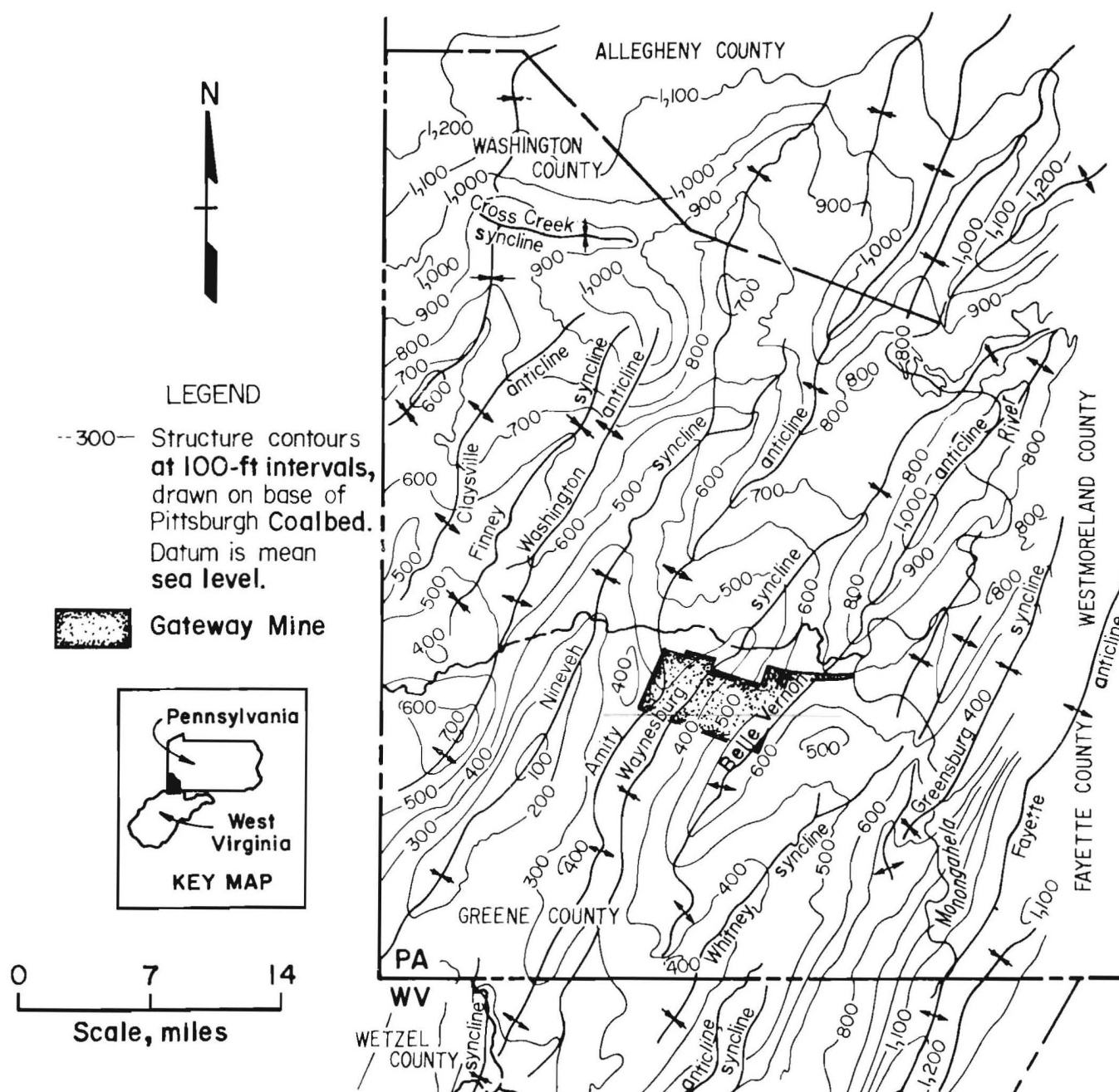


FIGURE 2.—Structural contour map of Pittsburgh Coalbed in Gateway Mine and southwestern Pennsylvania (2).

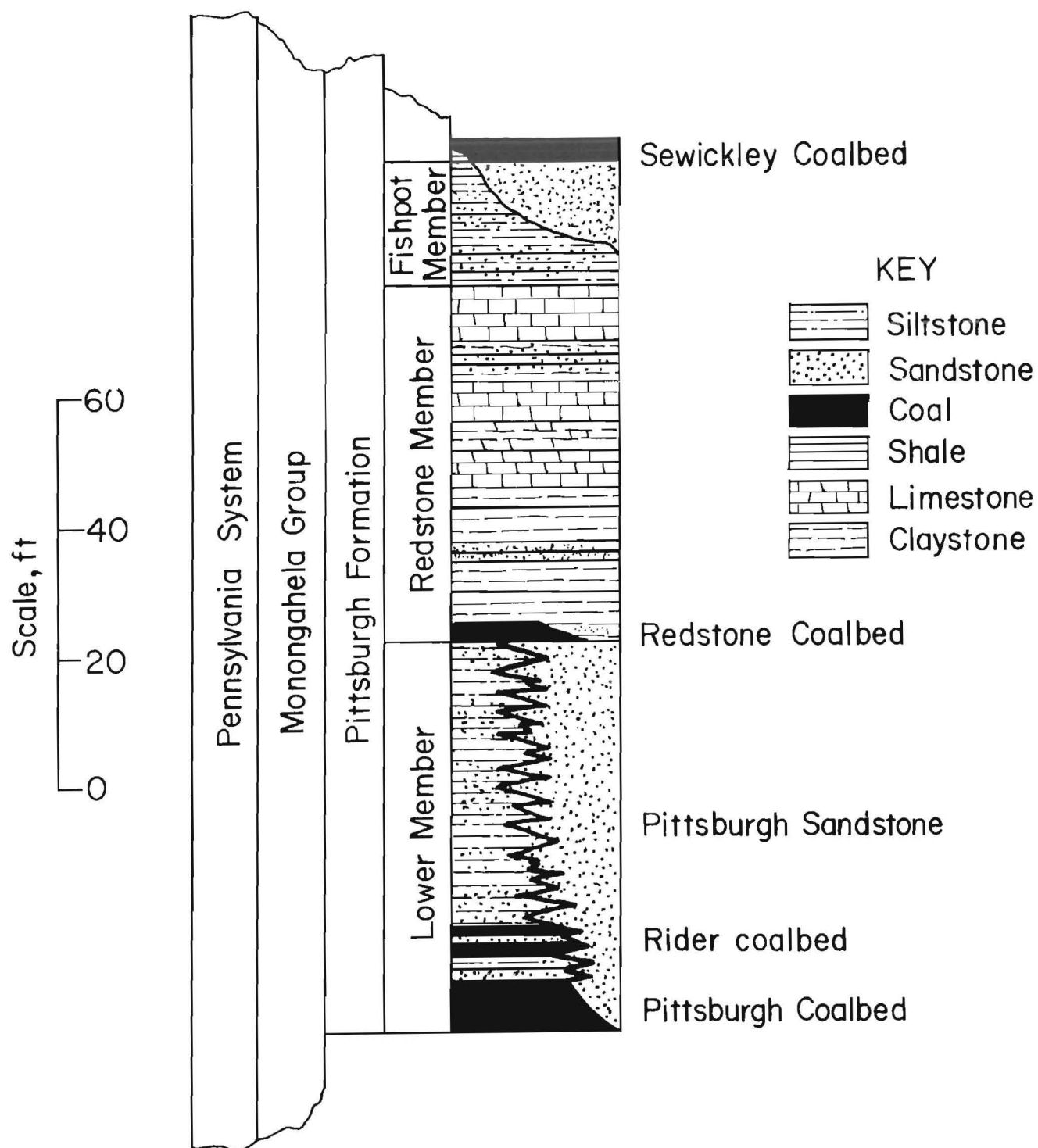


FIGURE 3.—Generalized stratigraphic column, based on exploratory borehole data and underground measurements within study area.

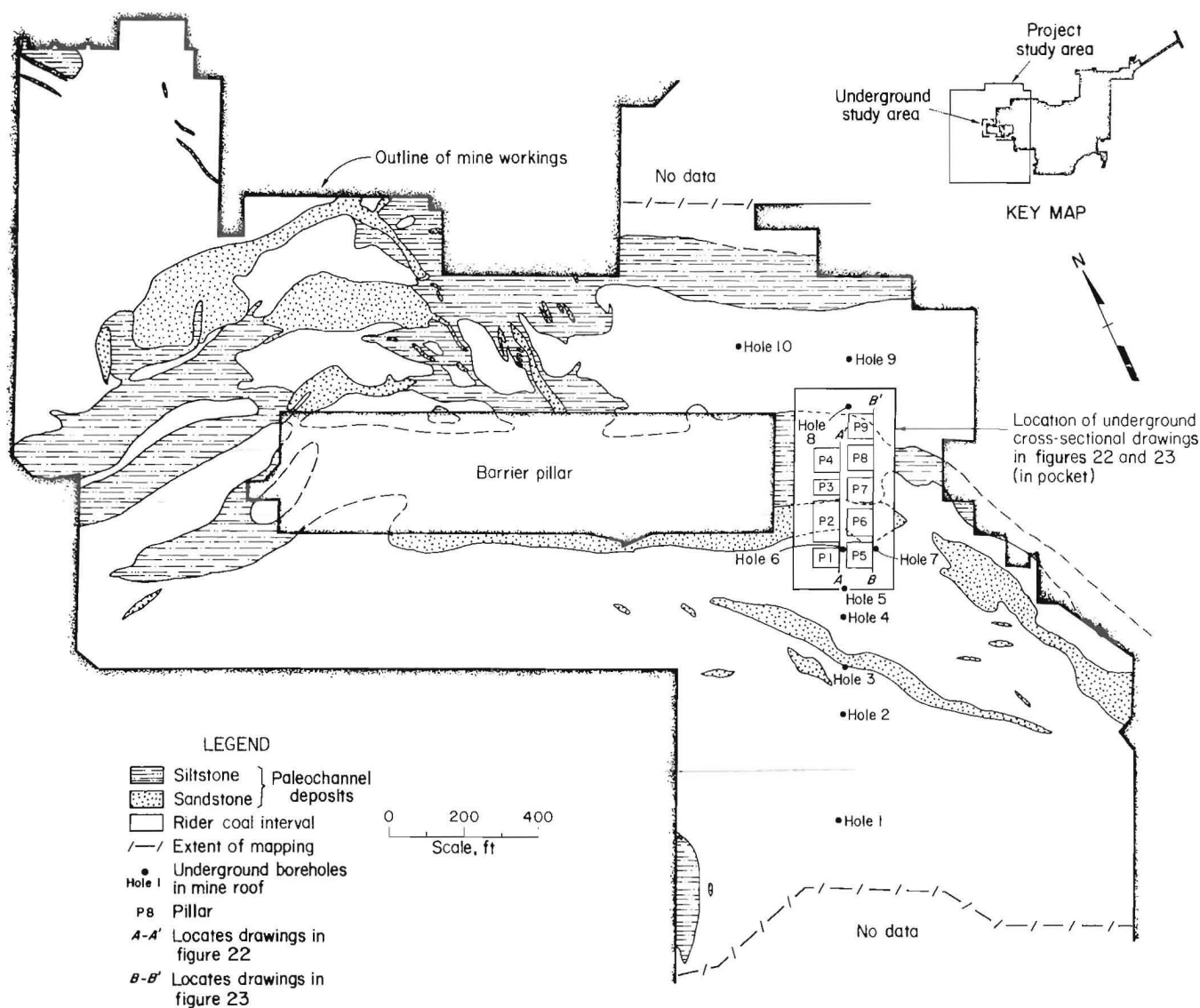


FIGURE 4.—Mine roof facies map of strata immediately overlying coalbed in underground study area.

material, and may contain light-gray sandstone streaks. As figure 4 indicates, paleochannels vary in size and geometry. Their linear extent ranges from 25 to 1,200 ft (7.6 to 366 m), while cross-sectional widths range from 2 to 175 ft (0.6 to 52.9 m). Paleochannel deposits range from 2 to 15 ft (0.6 to 3.6 m) in viewable thickness.

The distribution and geometry of the Pittsburgh Sandstone in southwestern Pennsylvania is illustrated in figure 5 (4-5). Previous work shows that these sediments were transported in a north-to-northwest direction (5). A roof rock facies map of the study area (fig. 6),

based on drill-log data and underground measurements, implies the same north-to-northwest depositional trend. A cross-sectional drawing constructed from drill-log data displays the complex lateral transitions of lithologies in the immediate mine roof (fig. 7).

The rider coal interval ranges in thickness from 0 to 11 ft and consists of interbedded shales and coals of variable thickness. A shale unit normally occurs at the base of the rider coal interval and is commonly called a binder or draw slate. During development, this shale unit is usually mined with the Pittsburgh Coalbed, leaving a rider

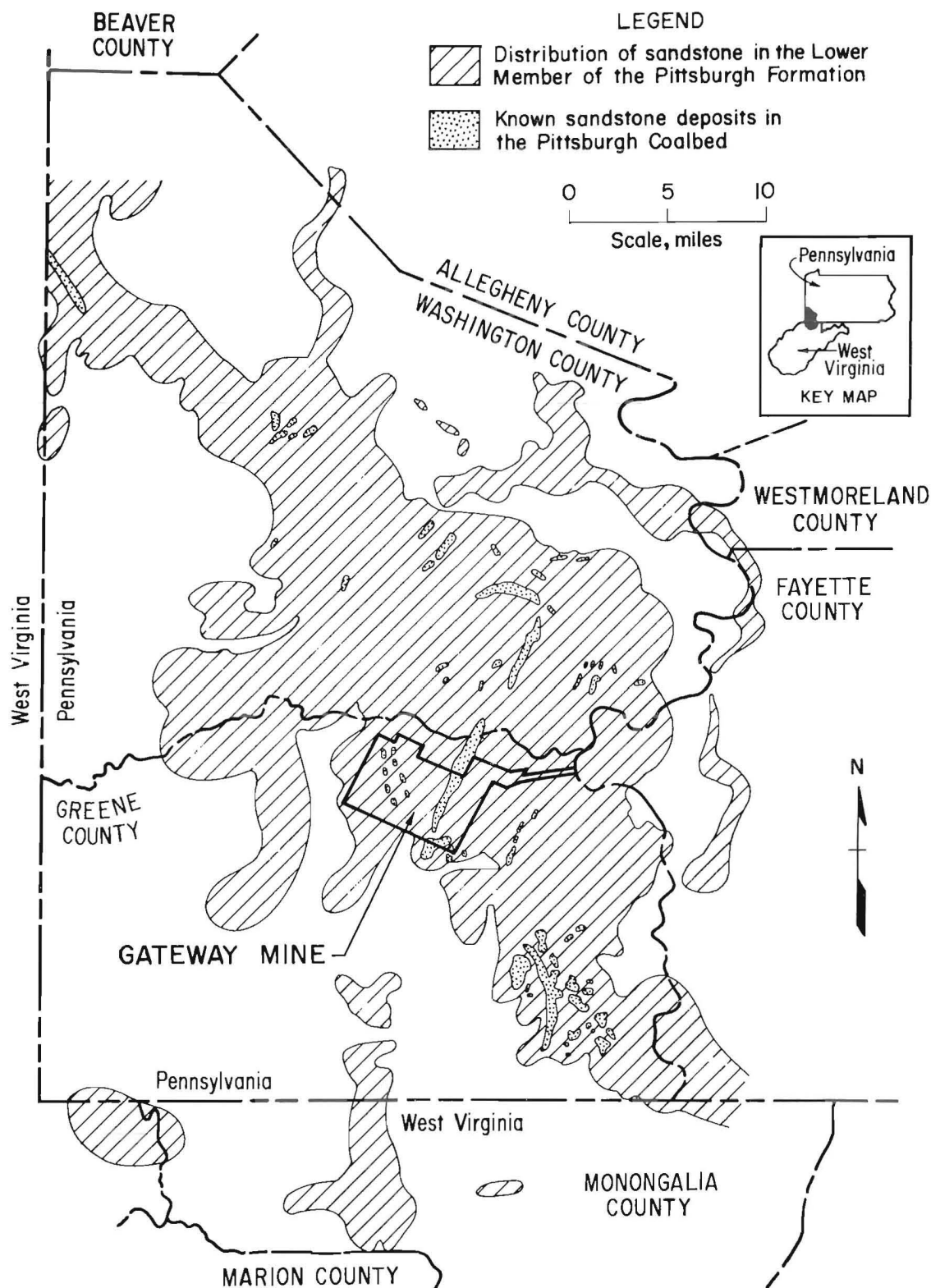


FIGURE 5.—Regional distribution of Pittsburgh Sandstone and known sandstone deposits (wants) in the Pittsburgh Coalbed (4-5).

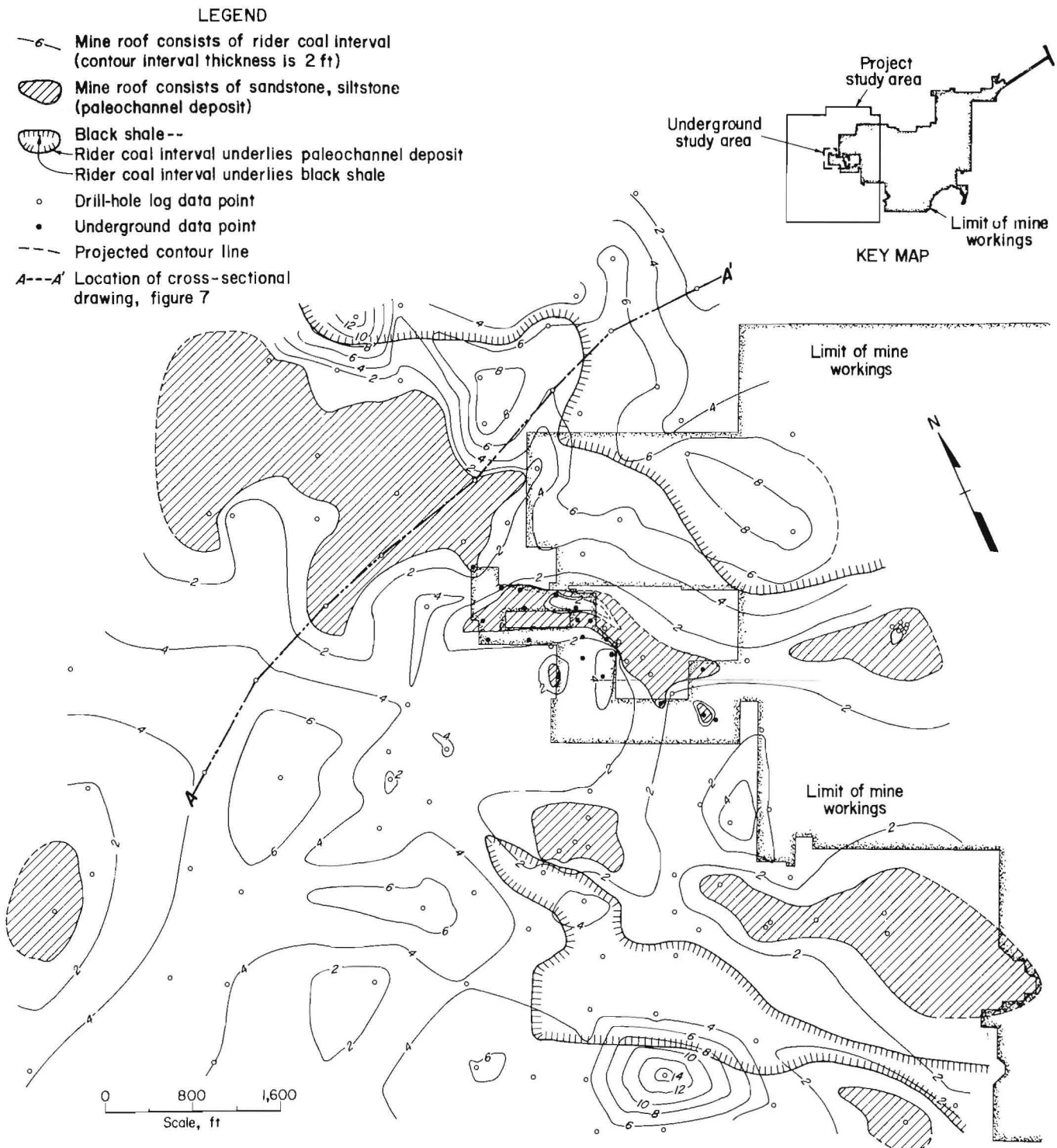


FIGURE 6.—Mine roof facies map of strata immediately overlying the coalbed in study area.

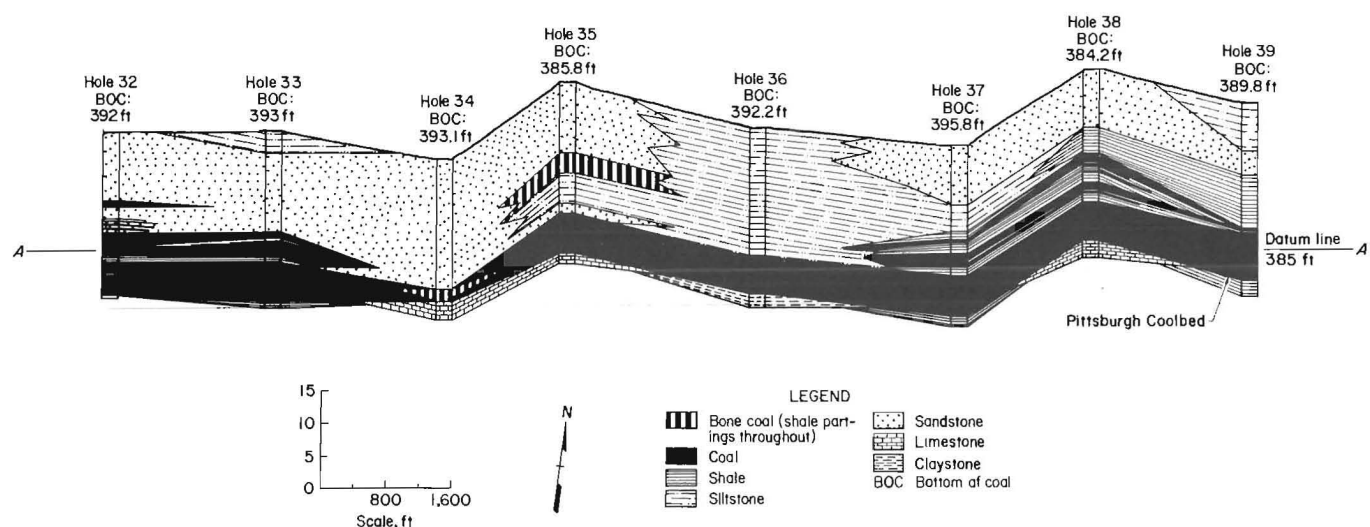


FIGURE 7.—Stratigraphic cross section through a paleochannel deposit. (See figure 6 for exact location.)

coalbed as the immediate roof. The rider coalbed prevents moisture from entering into and deteriorating the overlying shale units. Occasionally, there is no draw slate in proximity to larger paleochannels. In some of these cases, the rider coalbed is directly above the main bench, producing abnormally thick coal (fig. 8). When the rider coal interval occurs without anomalies, good mining conditions and stable roof are usually present.

Underground observations also indicate that the paleochannel deposits and the rider coal interval were deposited during the same time period (contemporaneously). Figures 9 through 11 display the multiple lateral and vertical stratigraphic combinations between the rider coal interval and the paleochannel deposits. These figures illustrate a lens-shaped deposit, horizontal bedding within the individual units, and a lack of soft sediments or flow structures.

PALEOCHANNEL CHARACTERISTICS AND THEIR EFFECTS ON THE PITTSBURGH COALBED

Paleochannels at the Gateway Mine have eroded and/or displaced as much as 100 pct of the Pittsburgh Coalbed in many places. Erosion occurred when the ancient streams cut into the already deposited peat (Pittsburgh Coalbed), carrying it away and then redepositing stream channel sediments. An example of this is shown in figure 12, where bedding planes in the coalbed are truncated by the channel deposit. Generally, channel deposit troughs are either U- or V-shaped in cross section. Other evidence of stream erosion is the presence of channel lag deposits (fig. 13).

Coalbed displacements associated with paleochannels are the direct result of differential compaction. Peats, muds, silty muds, and sands are reduced from

their original bulk volume during compaction by the weight of overlying sediments. The percent volume reduction depends on the depth of burial and the type of sediments being compacted. For example, it is estimated that at a burial depth of 2,000 ft, peat is reduced by 95 pct during transformation into coal, mud by 35 pct into shale, and sand by 11 pct into sandstone (6). Differential volume reduction around relatively unyielding paleochannel deposits caused the surrounding sediments to be deformed. Differential compaction between the rider coal interval, paleochannel deposits, and the Pittsburgh Coalbed formed slip planes, faults, clay-dike faults, clastic dikes, rolls, and slump structures.

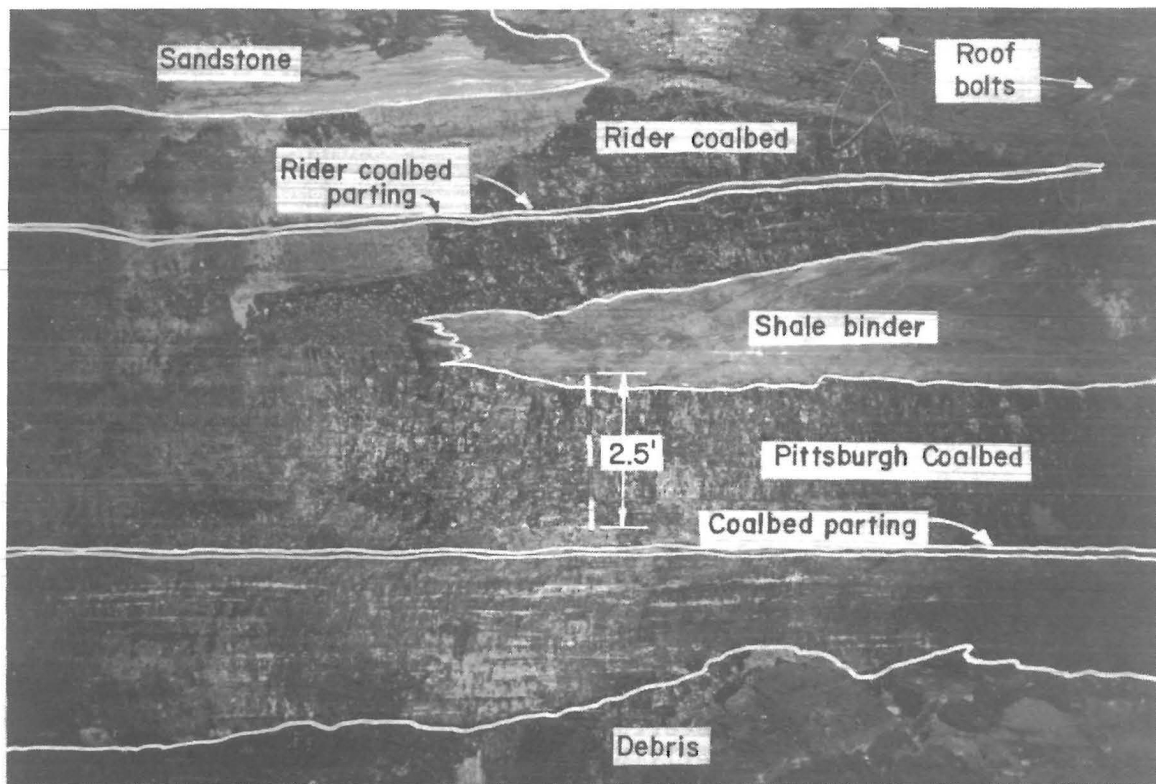


FIGURE 8.—Unusually thick deposit of coal, due to the absence of shale binder (part of rider coal interval).

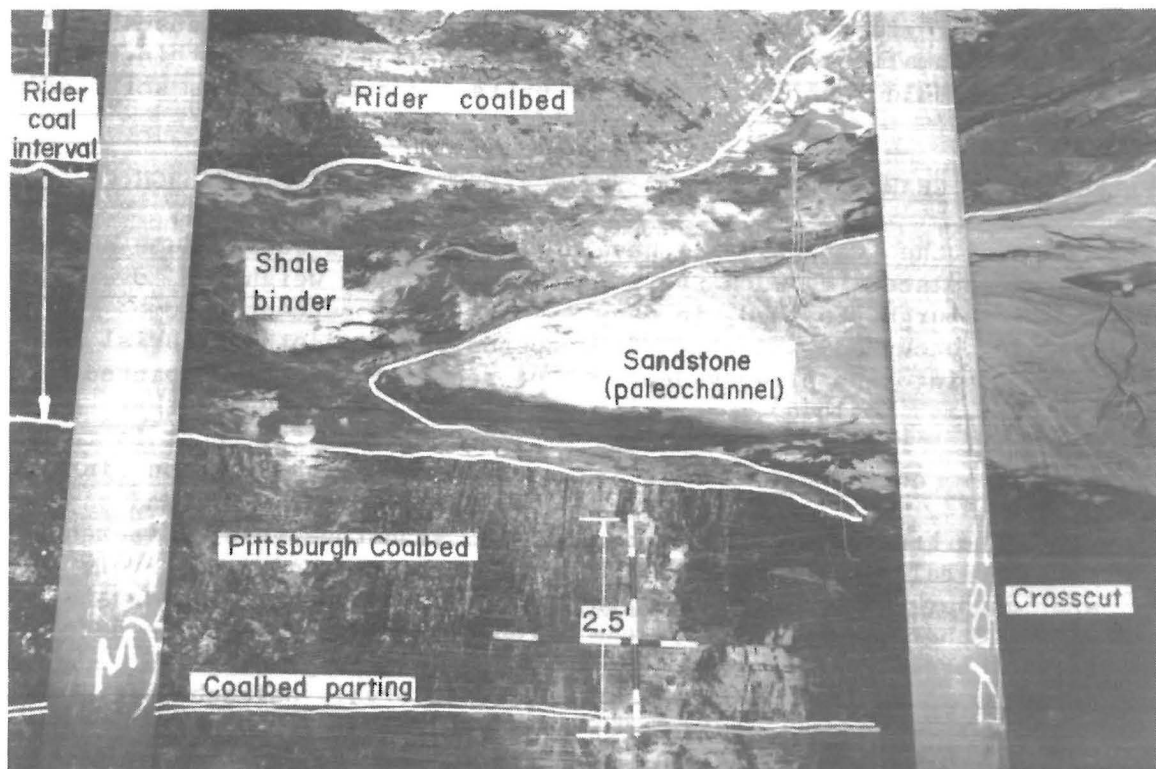


FIGURE 9.—Lens-shaped sandstone deposit (paleochannel) situated in shale binder (part of rider coal interval).

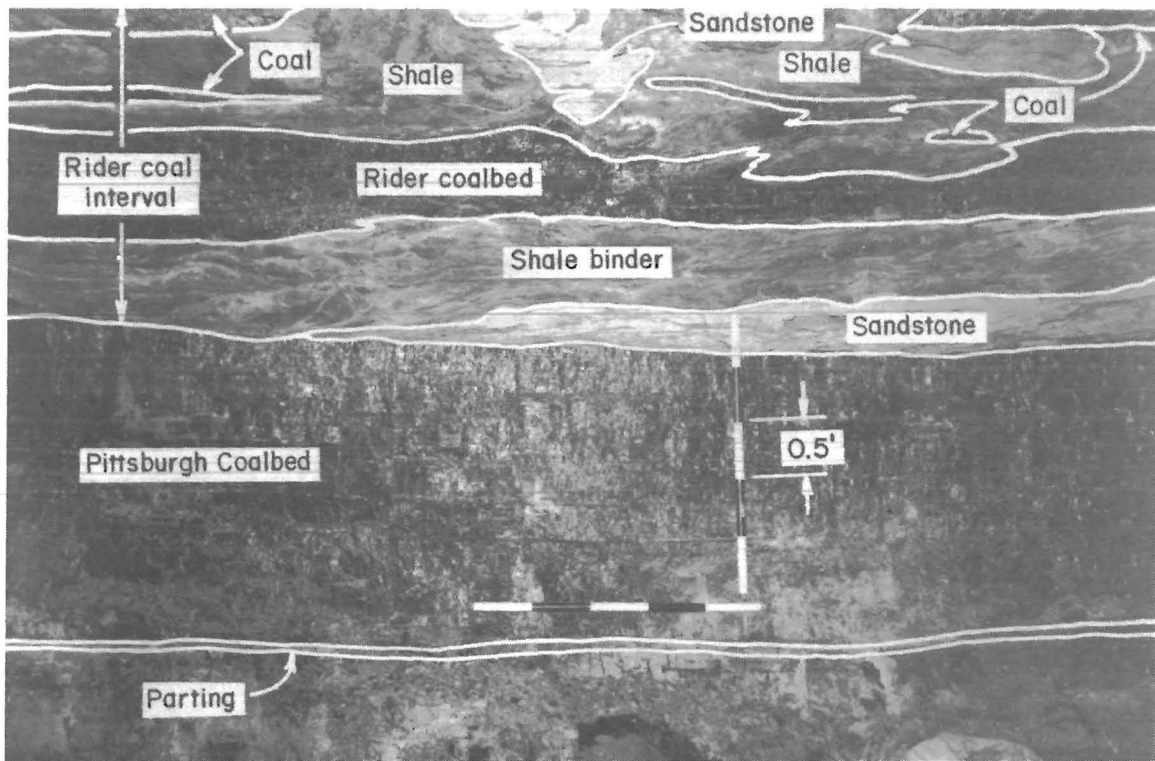


FIGURE 10.—Nonerosional sandstone deposit uniformly pinching out between coal and shale binder.

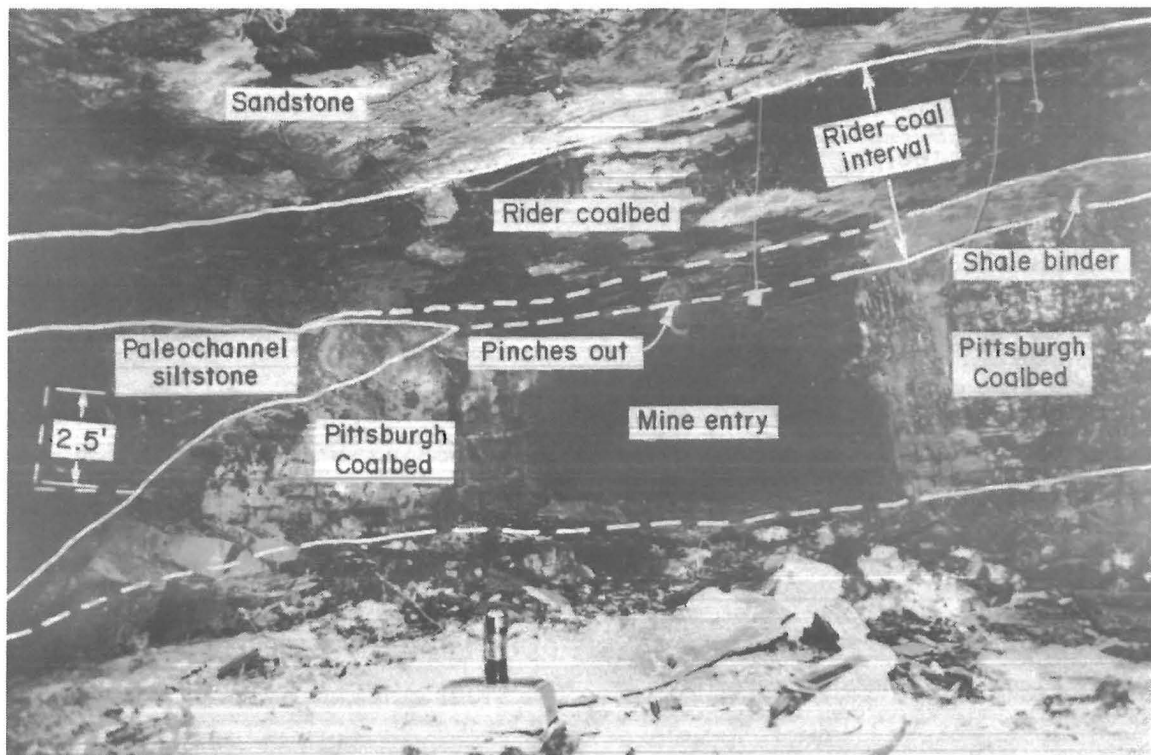


FIGURE 11.—Trough-shaped siltstone deposit underlying a nondisturbed rider coalbed.

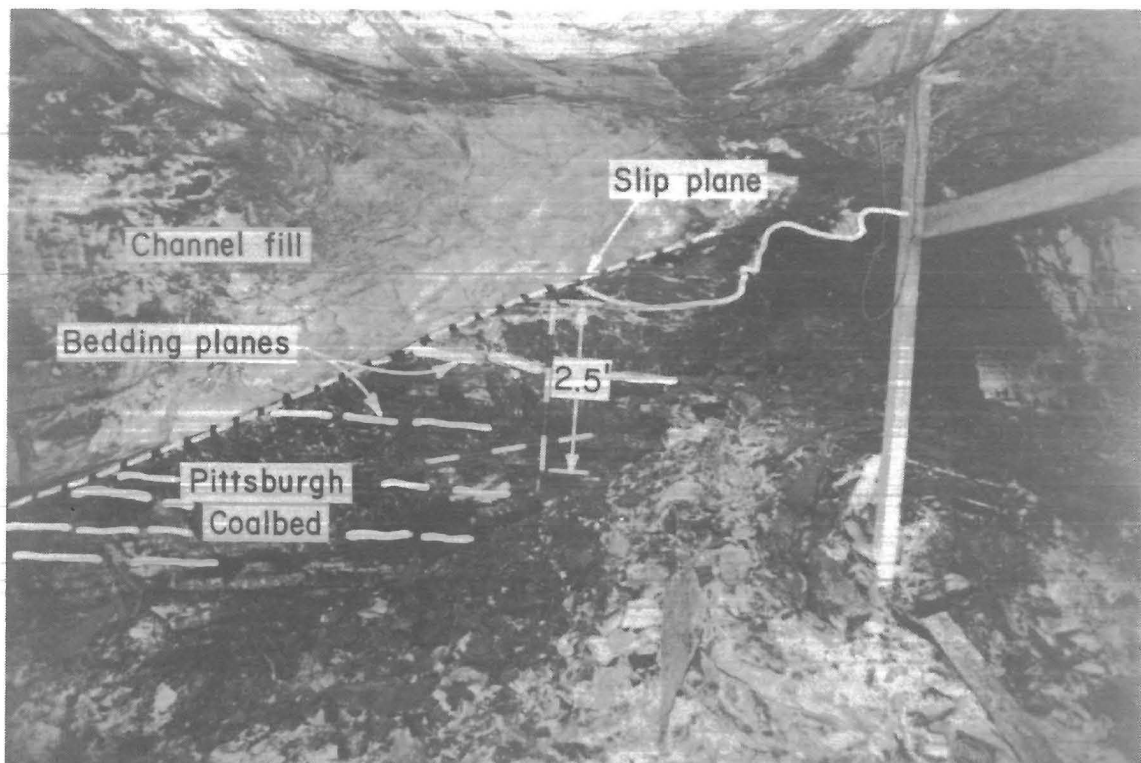


FIGURE 12.—Truncated coalbed bedding planes caused by erosional siltstone deposit.

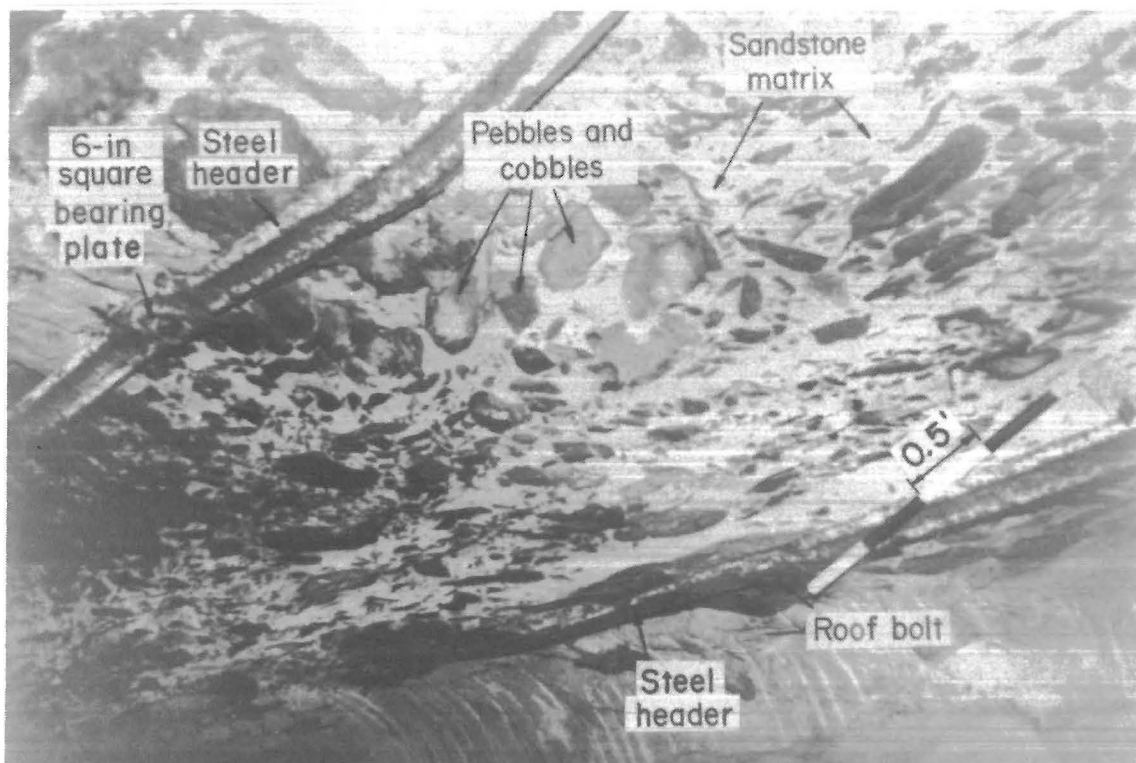


FIGURE 13.—Erosional channel lag deposit at the base of a sandstone deposit. (Pebbles and cobbles consist of shale.)

Two-thirds of the slip planes and faults mapped occur within paleochannel deposits (fig. 14). These planes display a preferred orientation parallel to paleochannel trends. Slip and fault planes observed in the mine roof usually extend into the coalbed, and less frequently into the floor strata. These planes also occur along the rider coal interval and paleochannel contact as well as the sandstone-siltstone contact within the paleochannel deposit. Physically, these planes are curved and highly slickensided (fig. 15). Normal faults associated with paleochannels displace the coalbed as much as 5 ft (1.5 m) (fig. 16). Clay-dike faults (faults with clay filling) also parallel paleochannels (fig. 17). These structures resulted when the peat was displaced (faulted), pulled apart (lateral tensional separation), and then infilled by overlying sediments.

Clastic dikes occur both parallel and perpendicular to paleochannel deposits (fig. 18). All clastic dikes mappable over 50 ft (15.2 m) in length occur within 50 ft of a paleochannel. Thirteen of the sixteen clastic dikes occur along the margins of the two largest paleochannels. Clastic dikes vary in composition and geometry. Most of them are composed of altered, dark-gray clay-size sediments that originated from the mine roof. However, a few are infilled with sediments similar to those in the floor (fig. 19). As figure 18 indicates, most of the dikes are linear to curvilinear in trend. They range in width from a few inches to several feet. The more continuous clastic dikes penetrate through the coalbed and into the floor.

A convex upward coalbed roll occurs along one or both flanks of paleochannel deposits (fig. 20). As the roll is approached, the coalbed rises in elevation and eventually dips down towards the paleochannel trough. The crest or axis of the roll parallels the channel trough (fig. 21). The amplitude of the roll is controlled by the size of the deposit. For example, along line A-A' in figure 21, the base of the coalbed rises 15 ft

(4.5 m) within a horizontal distance of 50 ft (15 m) (17° dip).

Detailed cross-sectional drawings through one of the larger paleochannels were constructed to illustrate the deformation and other structures associated with slumping (figures 22 and 23, in pocket). The locations of the cross sections are shown on figure 4. The two cross-sectional drawings form a composite view of the paleochannel along two entries. The paleochannel illustrated in these drawings measures 175 ft (53.4 m) in width where it displaces the coalbed. It is 350 ft (106.7 m) long and 14.5 ft (4.4 m) in viewable thickness. The folded coalbed and small- and large-scale slip and fault planes on the southwest side of the paleochannel reflect a rotation and overturning movement (slumping) (pillar 2 in figure 22 and pillar 6 in figure 23). The folded coalbed appears to have nearly the same volume dimensions as the area now occupied by the paleochannel deposit. An indication of slumping on the northeast flank of the paleochannel (pillar 3 in figure 22 and pillar 7 in figure 23) is a continuous glide zone along the contact between the coalbed and siltstone roof. This glide zone has slickensides and is striated in a northeast-southwest direction. The less compacted paleochannel deposit also squeezed the coal and underclay into a larger roll, which parallels the paleochannel axis on the southwest side (fig. 21). Soft sediment deformation as evidenced by the contorted interfingering of the sandstone, siltstone, and coal suggests that slumping occurred before lithification. Inclined bedding planes and normal faulting on the southwest flank of the structure imply further deformation after slumping.

An overview of these drawings indicates that a portion of the exposed paleochannel deposit slumped into the coalbed from the northeast to the southwest before the sediments lithified. Continued burial and compaction further deformed and displaced these sediments into their present positions.

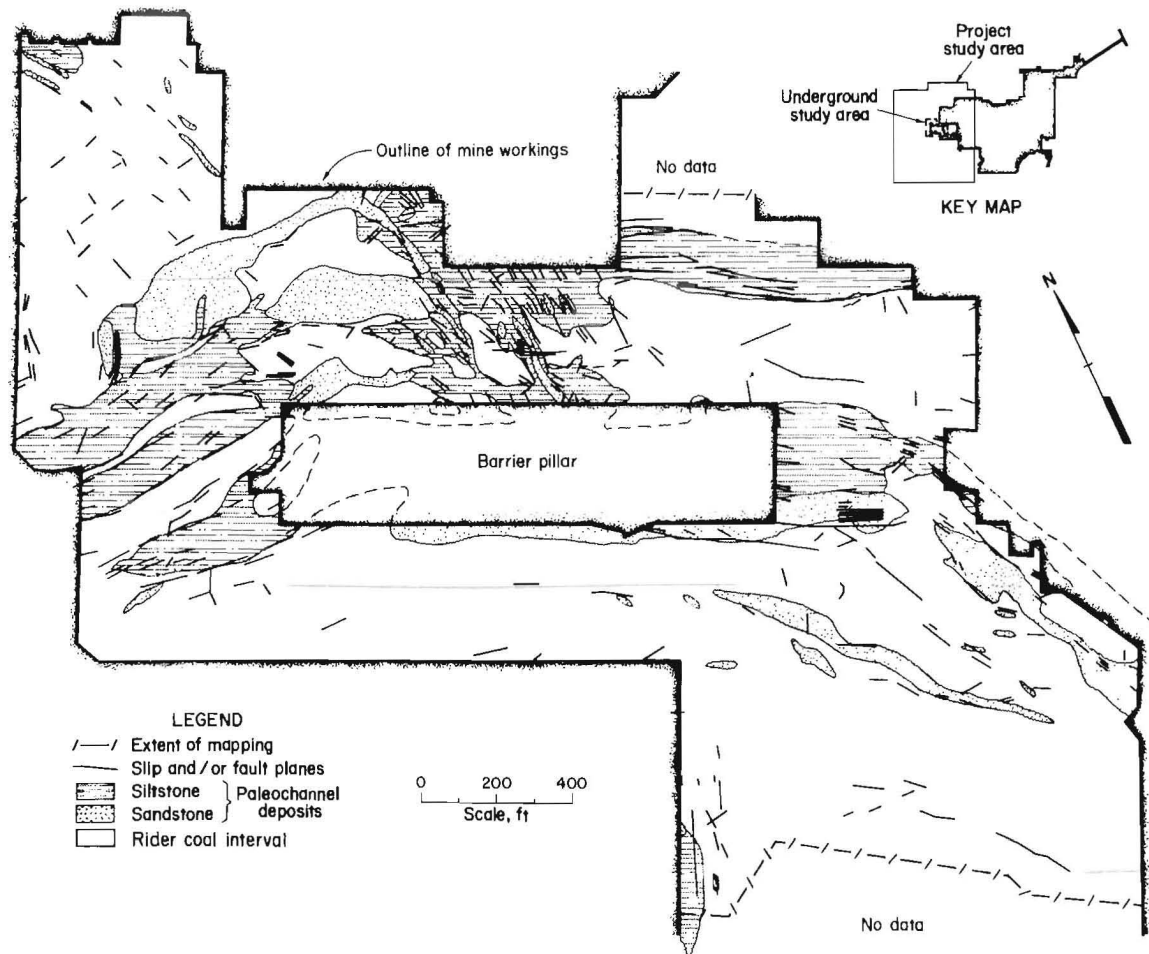


FIGURE 14.—Slip and fault plane locations in underground study area.

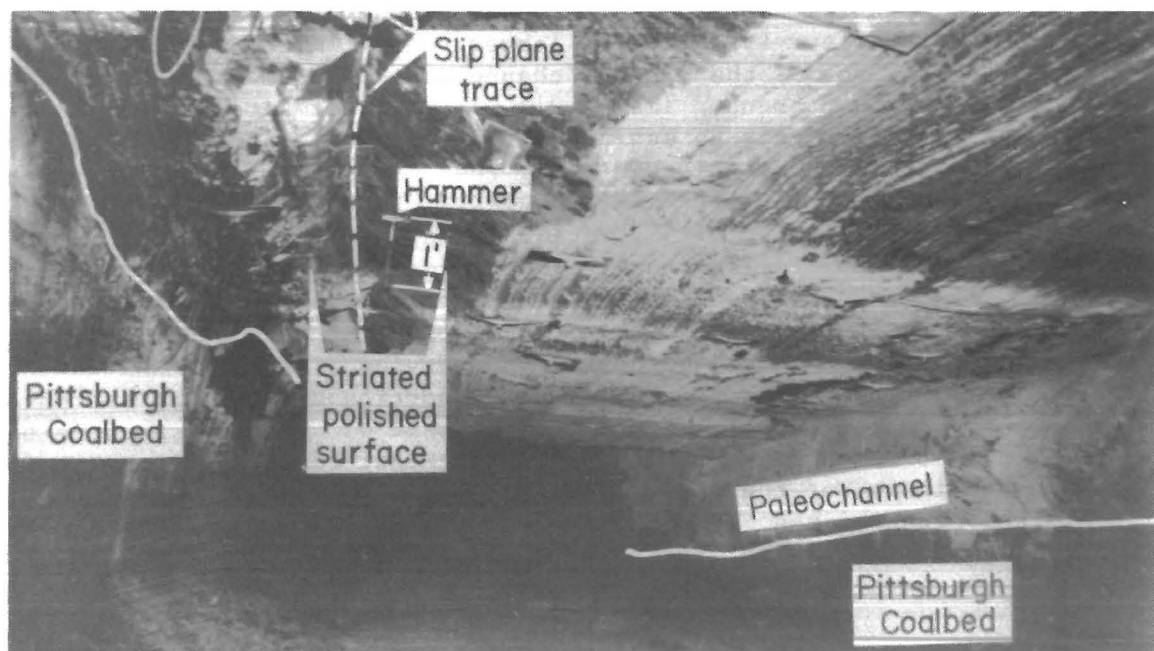


FIGURE 15.—Slip plane with slickensides running parallel along margin of paleochannel.

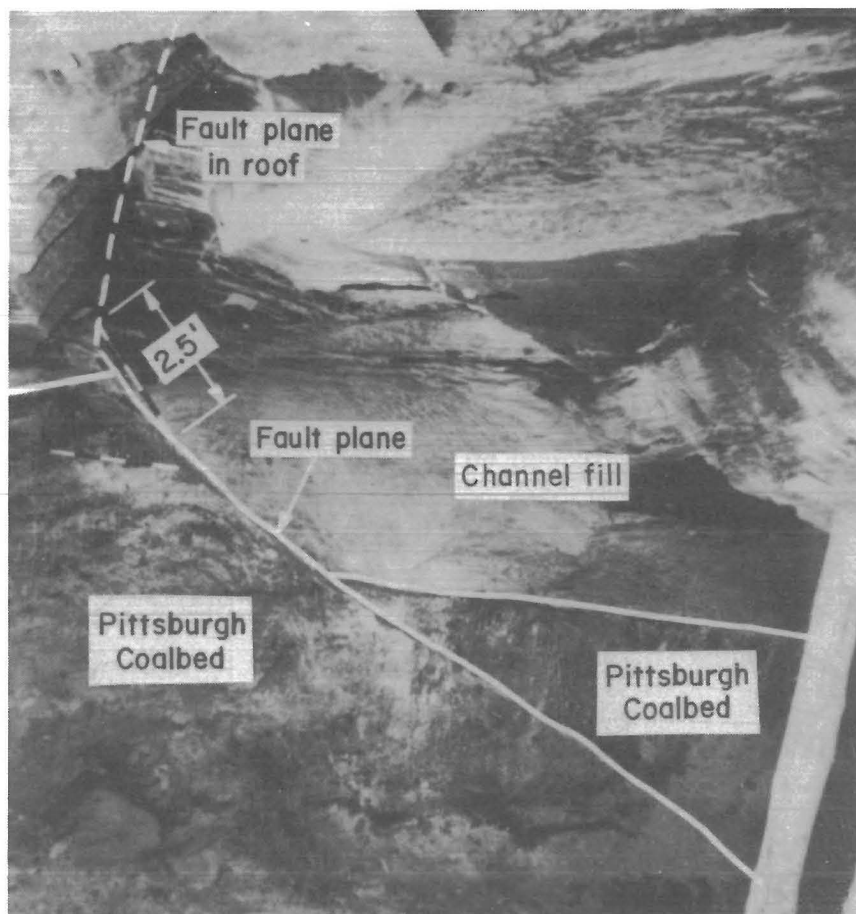


FIGURE 16.—Typical example of normal faulting that occurs along flanks of paleochannel deposits.

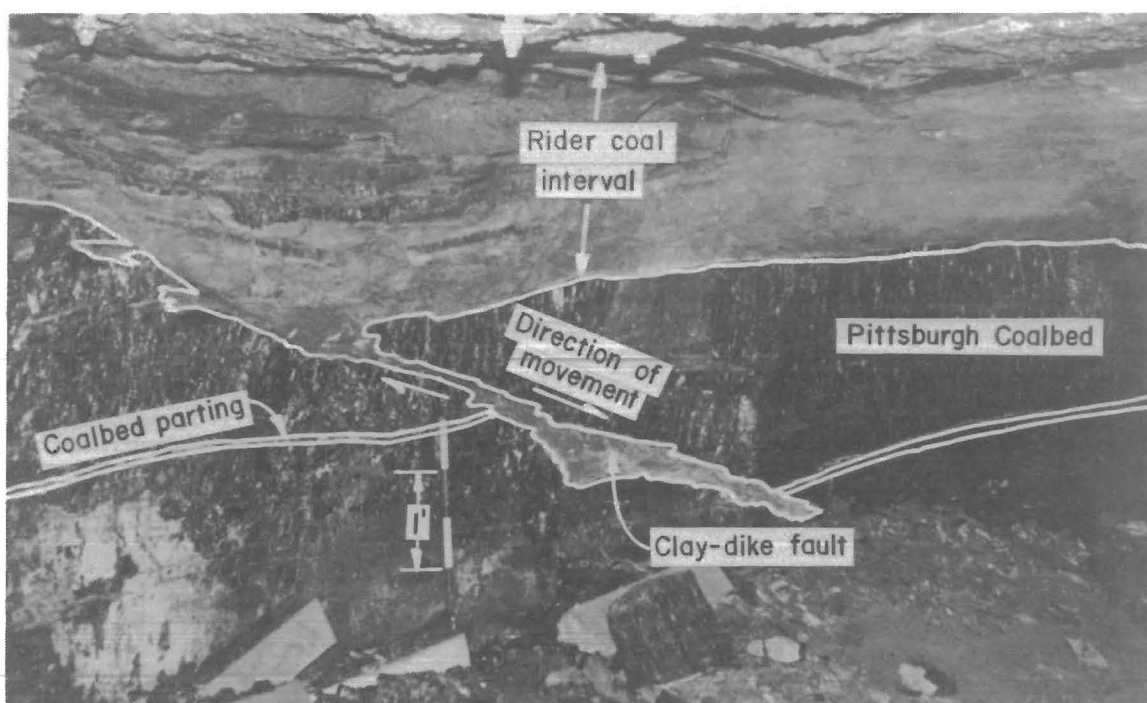


FIGURE 17.—Clay-dike fault commonly associated with differential compaction.

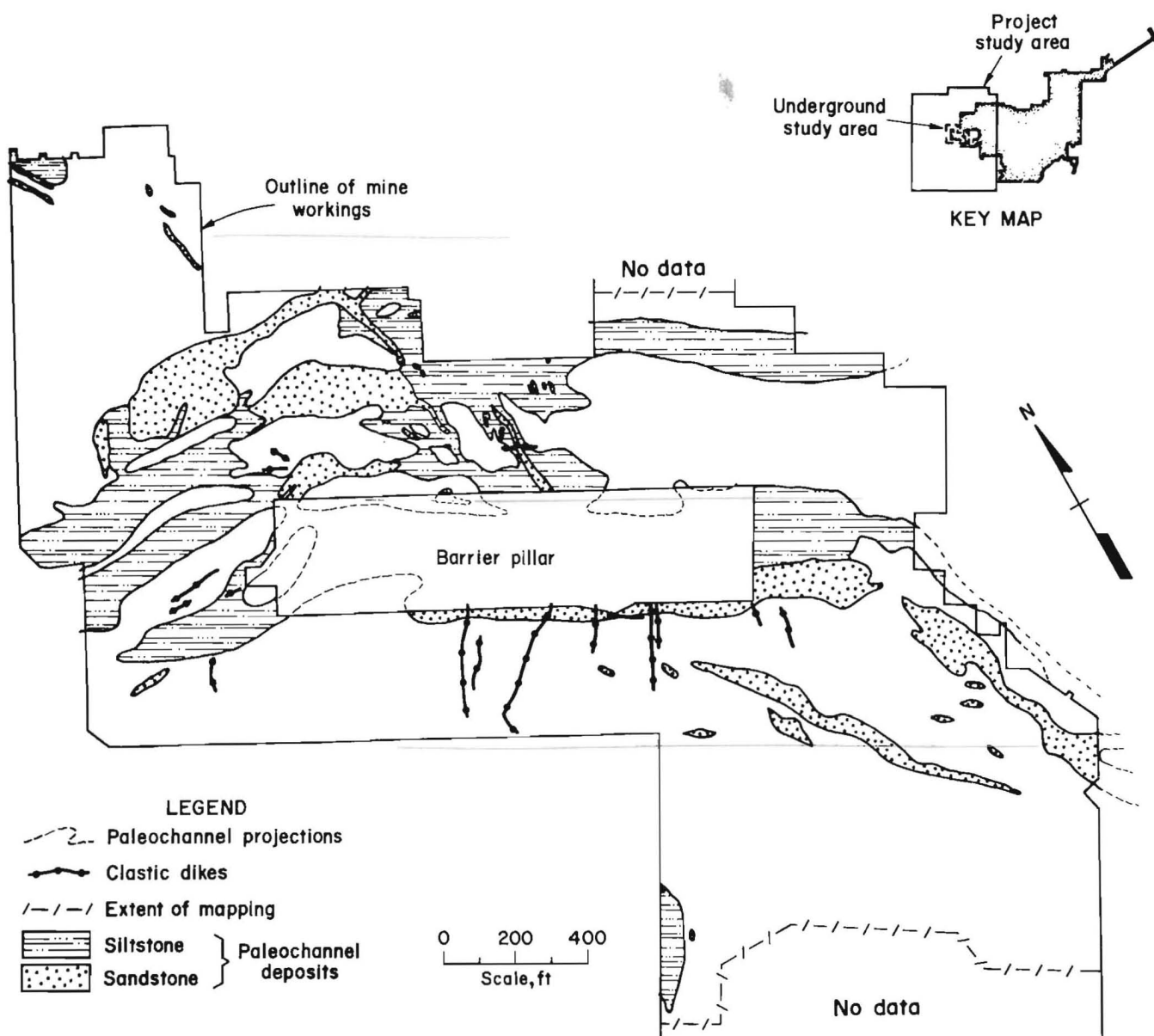


FIGURE 18.—Location of clastic dikes associated with paleochannel deposits in underground study area.

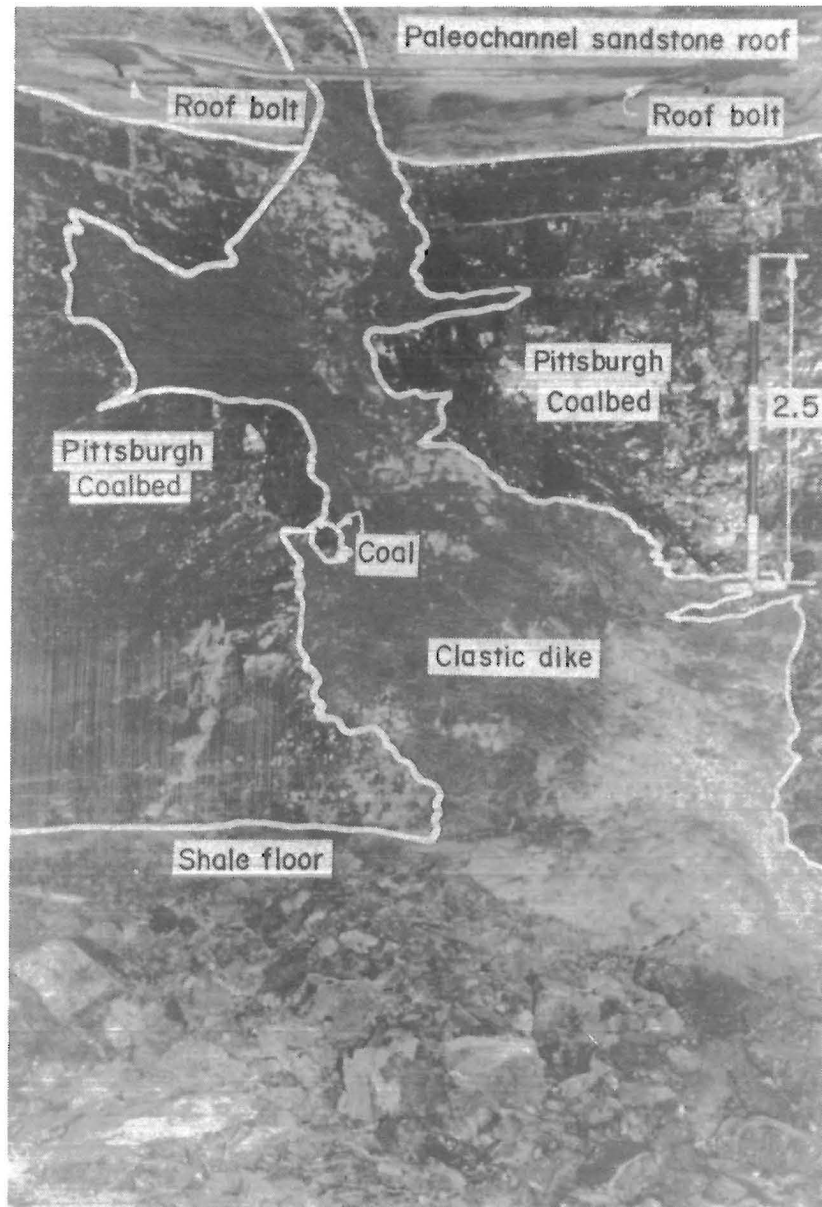


FIGURE 19.—Clastic dike infilled with sediments from floor strata.

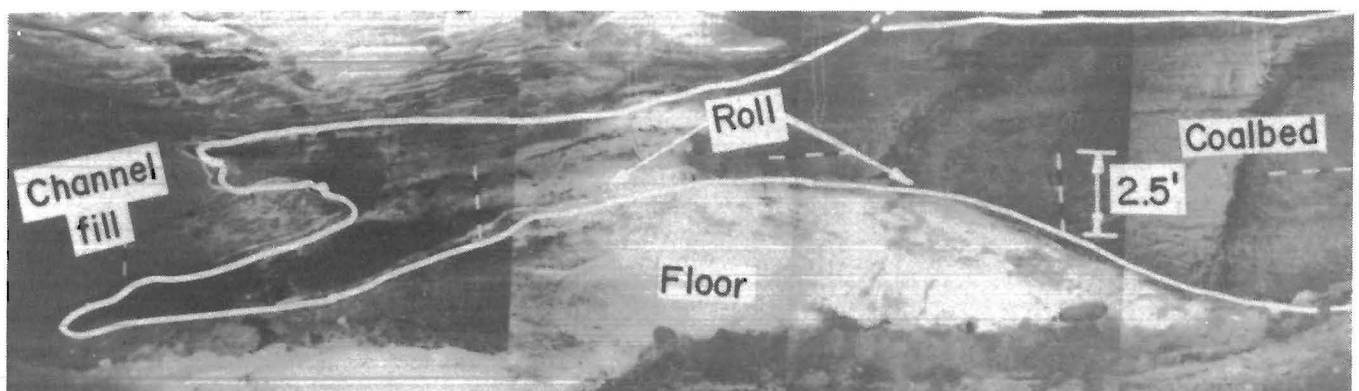


FIGURE 20.—Small-scale coalbed roll along flank of channel fill deposit (composite photograph).

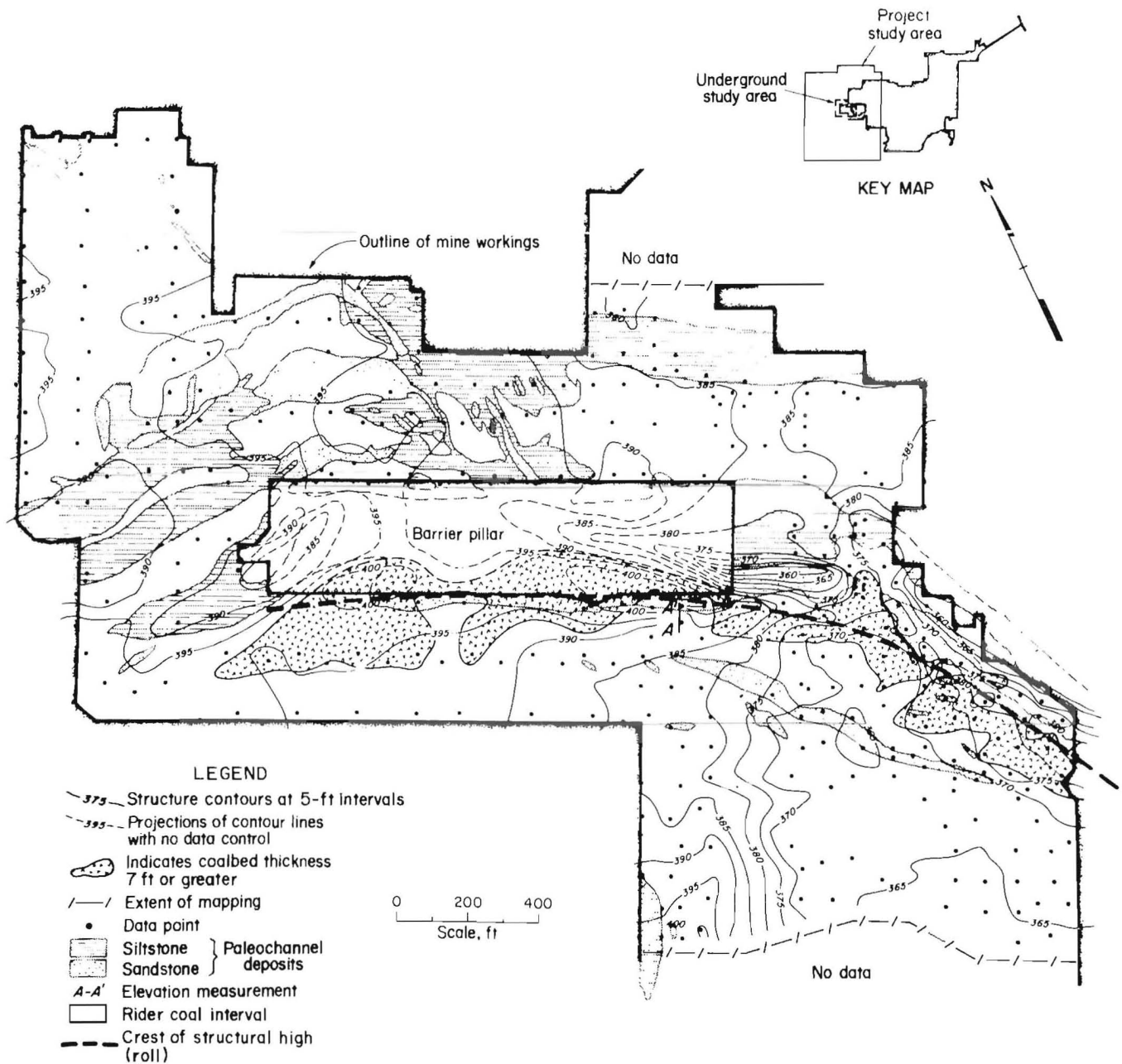


FIGURE 21.—Structural contour map on base of Pittsburgh Coalbed in underground study area, showing crest of coalbed roll.

MINE ROOF STABILITY

The various sedimentary and structural features that affect mine roof stability at Gateway Mine are shown in figure 24. A subjective classification scheme divides the immediate mine roof characteristics into three categories: (1) good, (2) heavy and spalling, and (3) fallen.

1. Good Roof. - Roof with no unusual spalling or sagging. Mine roof surface is fairly planar and/or has the original configuration cut during mining.

2. Heavy and Spalling Roof. - Heavy, sagging roof that has an uneven rough configuration due to unrestrained spalling (figs. 25-26). Excessive loading and sagging as observed in squeezed cribs and split or bowed posts and crossbars.

3. Fallen Roof. - An unexpected roof fall that requires cleanup.

Entries located under paleochannel deposits are less stable than entries where the rider coal interval is present.

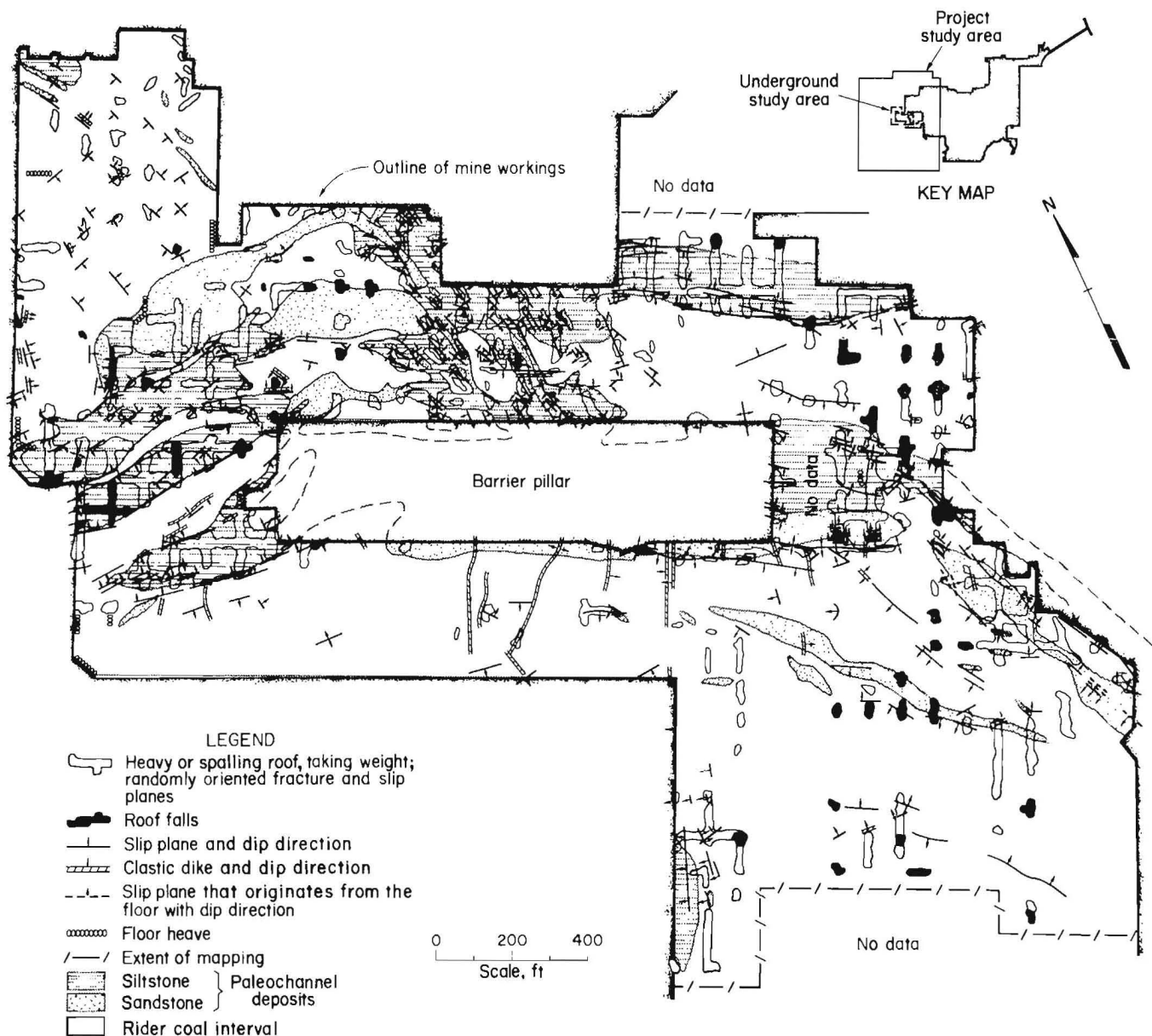


FIGURE 24.—Hazardous mine roof associated with channel deposits in underground study area.



FIGURE 25.—Spalling mine roof.



FIGURE 26.—Heavy and spalling mine roof.

One-fourth of the total 28.5 acres of roof mapped is classified as "heavy and spalling" and/or "fallen." One-half of such roof occurs within paleochannel deposits, which comprise about one-fourth of the total mapped area. Table 1 shows that more than 50 pct of the siltstone roof is classified as "heavy and spalling" and/or "fallen." However, it is important to note that portions of the roof fitting these designations are the weak transition zones between different lithologies. As figures 22 through 24 illustrate, the vast majority of transition zones are located within and adjacent to paleochannels.

Underground core drilling in the mine roof was conducted to determine the unconfined uniaxial compressive strength of the rock types associated with paleochannels. Ten boreholes were drilled approximately 11 ft (3.3 m) into the mine roof along a cross-sectional path through one of the larger paleochannels. Figure 4 shows the location of the boreholes. Rock quality designation (RQD) values³ for each borehole were confirmed using a fiber optical borehole stratascope. Recovered core samples having a minimum length-to-diameter ratio to 2:1 were tested for unconfined uniaxial compression strength on a Tinius Olsen⁴ universal testing machine. Recovered core having a length-to-diameter ratio of 1:1 was tested for index values on a Terrametrics point-load testing apparatus, in the axial direction only. Procedures and calculations used to compute index values are based on Broch and Franklin's method

³See appendix for method of determining RQD values.

⁴Reference to specific products does not imply endorsement by the Bureau of Mines.

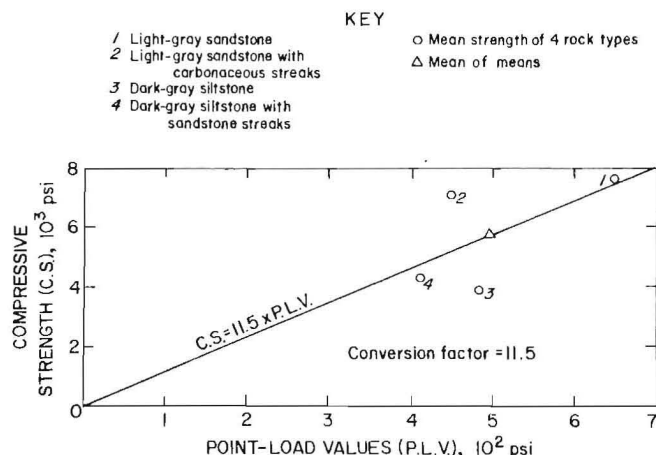


FIGURE 27.—Linear relationship between unconfined uniaxial compressive strengths and point-load index values of the mine roof lithology.

(8). Rock test results shown in table 2 indicate that the paleochannel sandstones and siltstones are stronger than the shales and coals in the rider coal interval. Coal samples from the rider coal interval had insufficient length-to-diameter ratio to be tested on the universal testing machine.

Only four out of seven lithologies were tested for both unconfined compressive strengths and point-load index values, because of the limited amount of core and inadequate core size. Ideally, this is not enough data to reasonably compare the unconfined compressive strengths for the different mine roof lithologies. However, previous studies (8-13) have shown that point-load index values can be used to estimate the unconfined compressive strength using a conversion factor. The conversion factor is based on an established linear relationship between the mean compressive strength and the mean point-load value of particular rock lithologies. For this study, a conversion factor of 11.5 was determined from the

TABLE 1. - Mine roof classification

Immediate mine roof lithology	Roof classification, pct			Total area, ft ²
	Good	Heavy, spalling	Fallen	
Paleochannel:				
Sandstone.....	72	26	2	9,292
Siltstone.....	39	56	5	18,125
Rider coal interval..	85	12	3	75,783
Total or average	76	21	3	103,200

equation (unconfined compressive strength = $11.5 \times$ point-load value) of a curve fit between the mean of the four mean rock strengths and the origin as shown in figure 27. Although these data are limited, an assumption was made that the conversion factor of 11.5 could be used to estimate unconfined compressive strengths from the tested index values. Table 3 lists the combined test strength values for all seven rock types. These results are compatible with those found in table 2.

Another approach to evaluating mine roof integrity, using the 11.5 conversion factor, was a comparison between the mean strength and RQD value of the rock

assemblage for each borehole. Figure 28 shows the positions of boreholes 1 through 6, 8, and 9 in relation to one another. The percentage of lithology tested is shown for each borehole in table 4. Mean strength values versus distance from the paleochannel suggest that the overall strength of the mine roof is weaker near paleochannels (fig. 29). This table is misleading and conflicts with results presented in tables 2 and 3 because the mean strength value for each borehole is based on the dominating lithology available for testing. These tested lithologies (table 4) do not necessarily represent the dominating lithology of that borehole.

TABLE 2. - Results of point-load and unconfined compressive strength tests

Mine roof lithology	Number of tests	Mean strength ¹	Standard deviation	Coefficient of variation, pct
POINT-LOAD TEST VALUES				
Paleochannel:				
Light-gray sandstone.....	70	4.4	1.2	28
Light-gray sandstone with carbonaceous streaks....	28	3.0	1.6	53
Dark-gray siltstone.....	6	3.3	1.1	34
Dark-gray siltstone with light-gray sandstone streaks.....	5	2.8	.8	29
Interbedded siltstone and sandstone.....	4	3.2	.3	9
Rider coal interval:				
Dark-gray shale.....	9	1.9	.5	27
Coal.....	7	.5	.2	51
UNCONFINED COMPRESSIVE STRENGTHS ²				
Paleochannel:				
Light-gray sandstone.....	24	7,684.7	1,677.2	22
Light-gray sandstone with carbonaceous streaks....	5	7,126.8	2,064.2	29
Dark-gray siltstone.....	6	3,892.9	397.4	10
Dark-gray siltstone with light-gray sandstone streaks.....	6	4,317.9	1,286.7	30
Interbedded siltstone and sandstone.....	1	5,363.0	NA	NA

NA Not available.

¹For point-load test values:

10.0, extremely high; 0.3-1.0, medium;

3.0-10.0 very high; 0.1-0.3, low;

1.0-3.0, high; 0.03-0.1, extremely low.

For unconfined compressive strengths: pounds per square inch.

²No data for rider coal interval.

TABLE 3. - Combined test strengths based on the 11.5 conversion factor¹

Mine roof lithology	Number of tests	Mean strength, ² psi	Standard deviation, ² psi	Coefficient of variation, pct
Paleochannel:				
Light-gray sandstone.....	94	7,520.7	1,980.4	26
Light-gray sandstone with carbonaceous streaks....	33	5,465.1	2,657.1	48
Dark-gray siltstone.....	12	4,733.7	1,598.8	34
Dark-gray siltstone with light-gray sandstone streaks.....	11	4,513.8	12,278.9	28
Interbedded siltstone and sandstone.....	5	5,343.6	373.6	7
Rider coal interval:				
Dark-gray shale.....	9	3,257.6	893.6	28
Coal.....	7	857.7	434.3	51

¹Linear relationship between unconfined compressive strengths and point-load index values.

²Based on unconfined compressive strengths and point-load index values.

TABLE 4. - Lithology tested in underground boreholes,¹ percent

Mine roof lithology	1	2	3	4	5	6	8	9
Paleochannel:								
Light-gray sandstone.....	13	85	58	78	64	45	9	75
Light-gray sandstone with carbonaceous streaks....	13	10	37	22	36	22	4	ND
Dark-gray siltstone.....	18	5	ND	ND	ND	ND	39	ND
Dark-gray siltstone with light-gray sandstone streaks.....	ND	ND	ND	ND	ND	ND	35	25
Interbedded siltstone and sandstone.....	ND	ND	ND	ND	ND	11	13	ND
Rider coal interval:								
Dark-gray shale.....	56	ND	ND	ND	ND	ND	ND	ND
Coal.....	ND	ND	5	ND	ND	22	ND	ND

ND No data. ¹As numbered in figure 28.

Based on all of the findings in this study, mine roof stability cannot be evaluated solely from the unconfined compressive strengths of the mine roof lithologies. Laboratory test results imply that the paleochannel deposits are more competent than the rider coal interval. However, underground observations indicate that, the rider coal interval obviously provides better roof conditions. These laboratory tests cannot consider

the overall structural integrity of the mine roof as it exists in underground conditions. In addition, evaluating mean strength data, based on the rock assemblage for each borehole, can be misleading when some of the variables are not considered. Mine roof stability classifications must incorporate both rock strength values and underground mapping with geologic interpretations to be accurate.

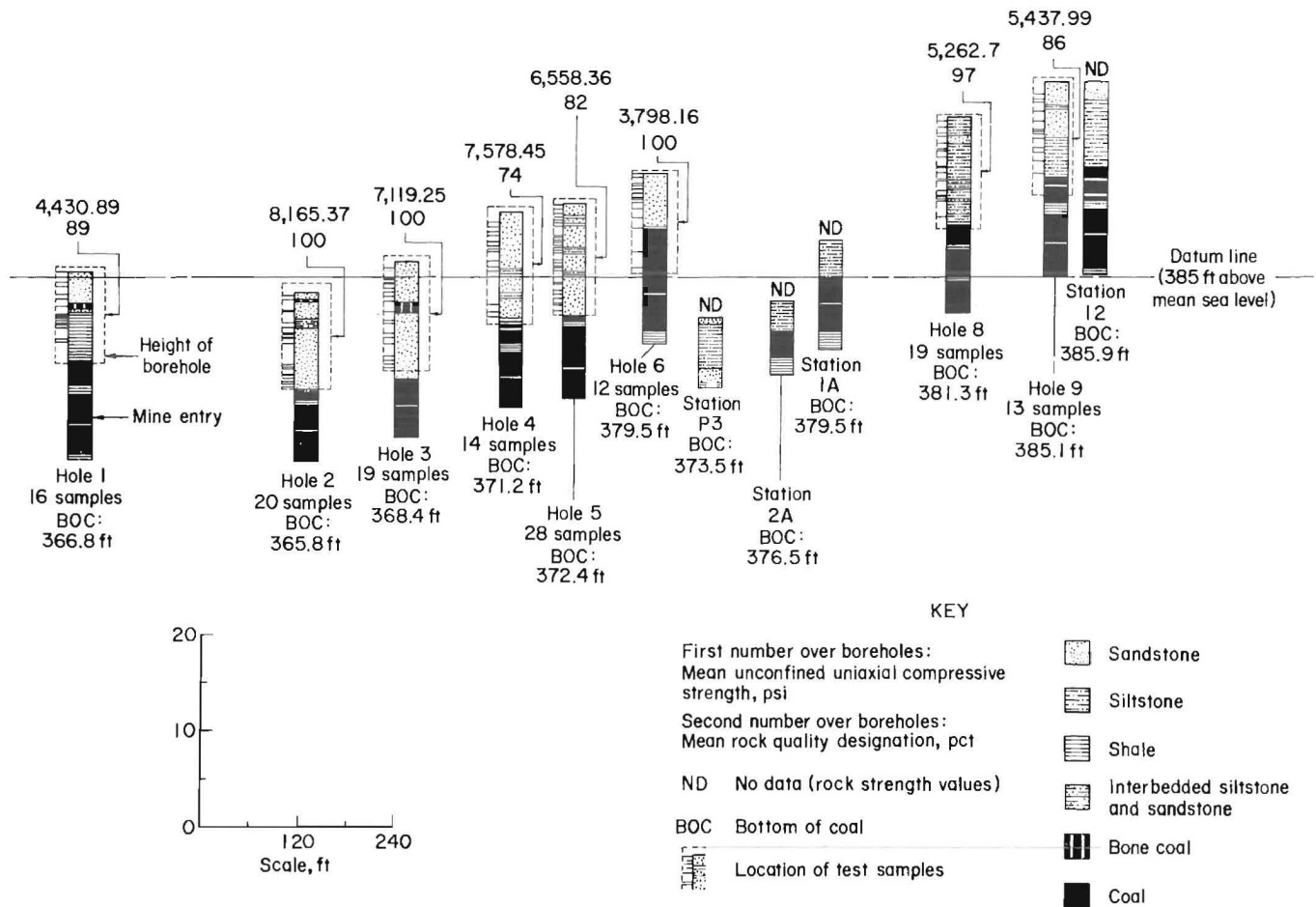


FIGURE 28.—Generalized stratigraphic columns of underground boreholes with sample locations, mean hole compressive strengths, and RQD values.

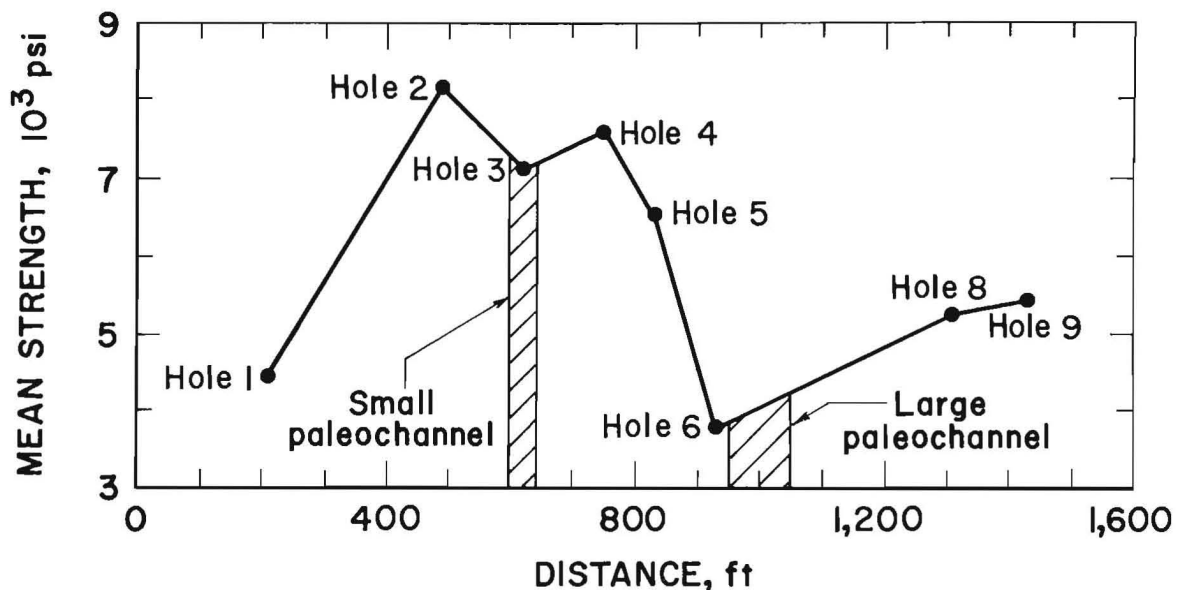


FIGURE 29.—Distance from paleochannel versus mean rock strength for underground boreholes shown in figure 28.

PALEOCHANNEL SUPPORT

Heavy and spalling roof associated with transition zones, coalbed rolls, and paleochannels requires additional support. Rock disturbances related to these features can be observed 20 ft (6.0 m) vertically into the main roof. As figure 30 indicates, angled and/or longer bolts would improve roof stability. Tensioned bolts help to compress loose fragmented roof associated with channel deposits, transition zones, and coalbed rolls. Mechanical bolts can be used, provided they are anchored into competent strata. In some areas at Gateway, mechanical bolts had to be 12 ft (3.7 m) long to reach competent strata. For this reason, the mine operator has changed to 5-ft (1.5-m) long tensioned rebar bolts, with proven success. Tensioned point-anchor resin bolts should also be effective in controlling this type of ground condition. Bolts in conjunction with cross-bars, steel mats, or wire mesh, installed

immediately after undermining paleochannels, could prevent spalling of immediate roof layers. Unstable roof associated with larger and more hazardous paleochannels may require steel sets, cribbing, or roof trusses.

Slip planes, faults, and clastic dikes associated with channel deposits also disrupt the lateral continuity of the immediate and, sometimes, the main roof. Unstable conditions are most severe when these structures are oriented parallel to or subparallel to the direction of face advance. Under these circumstances, the mine roof may be segmented into cantilever beams. The cantilever effect can be minimized by bolting and strapping together the roof on each side of the discontinuity to form an integral built-in beam. Slips, faults, and clastic dike orientations (strike and dip) should be considered when determining bolt length and angle of installation (fig. 31).

PREDICTION OF PALEOCHANNELS AND THEIR EFFECTS ON MINE PLANNING AND DEVELOPMENT

The presence of paleochannels and their impact on mine planning and development often go unrecognized during exploratory drilling. In many cases, the customary grid spacing of drill holes is not sufficient to detect the width, thickness, or linear extent of paleochannels. Drill-log data used in conjunction with underground mapping (14) are instrumental in predicting paleochannels in advance of mining. The absence or thinning of the coalbed is the most obvious effect of paleochannels on mining. Contouring coalbed thickness using data obtained from drill logs and underground measurements often identifies larger paleochannels and their trends (fig. 32). Analysis of coalbed sulfur content can also be used to identify probable paleochannel zones. In certain coal basins, abnormally high coalbed sulfur content often occurs adjacent to paleochannels (15).

Other evidence that can be derived from drill-log data to predict paleochannels includes an increase or decrease in coalbed thickness (fig. 33), a change in

coalbed elevation, and coalbed cleat rotation. In the study area normal coal thickness (5.8 ft (1.8 m)) increased as much as 4.5 ft (1.4 m) along the margin of one of the larger channel deposits. As previously mentioned, at Gateway Mine increases in coalbed thickness are due to the absence of the shale binder in the rider coal interval. This local increase in coal thickness coincides with a local change in coalbed elevation (roll shown in figure 21). Within these coalbed rolls, the face cleat rotated with respect to strike as much as 40° (figs. 22-23). The stereonets in figure 34 exhibit a wider variation in face cleat dip (as represented by changes in the width of the band between the opposite contour lines of zero point) within a 100-ft (30.5-m) zone surrounding paleochannels (fig. 35). Routine mining is disrupted along the flanks of steeply dipping rolls. Continuous miners and shuttle cars have difficulties negotiating 16° dips, especially when wet, soft floors are encountered. This aggravation is

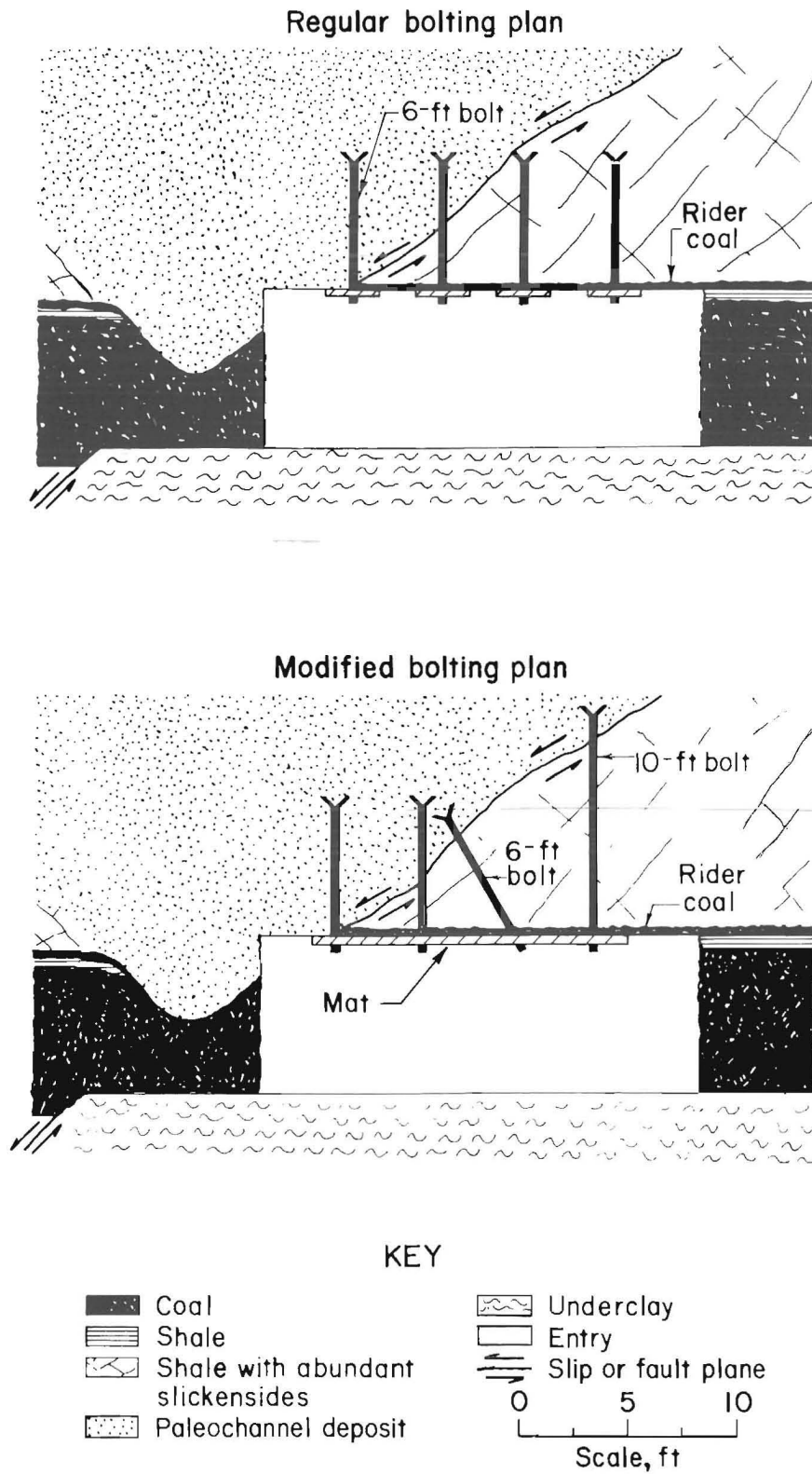
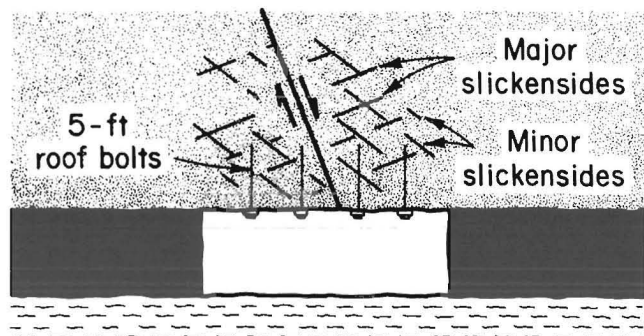
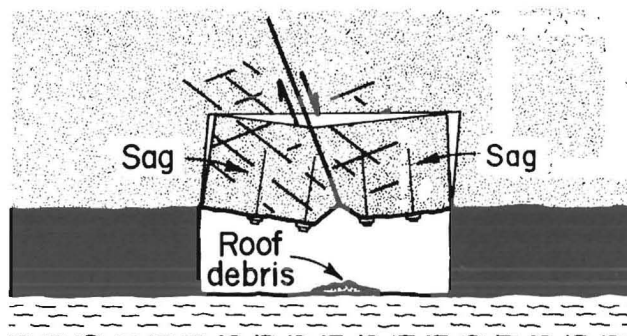
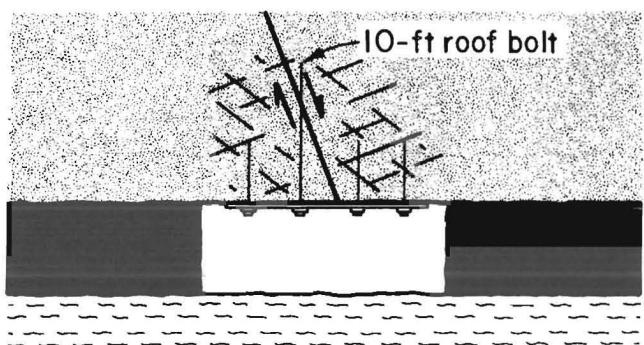
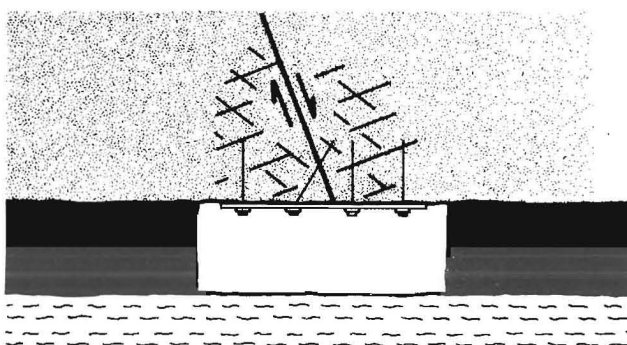


FIGURE 30.—Recommended roof bolting plan to increase roof stability along flanks of paleochannels.

A Ineffective bolting**B** Roof behaves as independent cantilever beams**C** Beam built by using longer roof bolt and mat**D** Beam built by using angled roof bolt and mat

KEY

	Roof		Pillar
	Entry		Slip, fault, or clastic dike
	Floor		

FIGURE 31.—Suggested roof bolting plan to support slip planes, faults, and clastic dikes commonly associated with paleochannels. *A* and *B*, ineffective bolting; *C* and *D*, effective bolting.

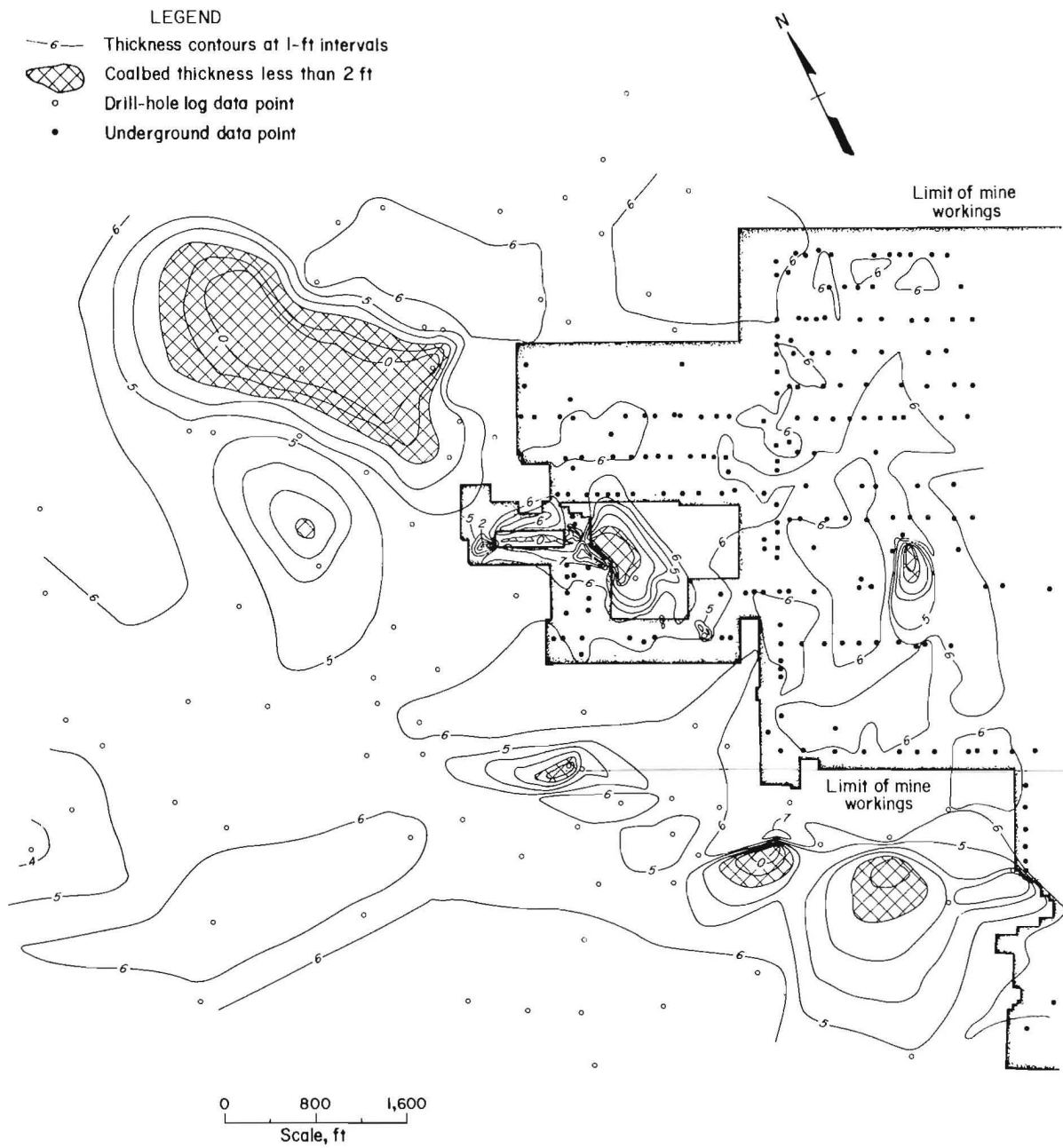


FIGURE 32.—Pittsburgh Coalbed isopach map of study area.

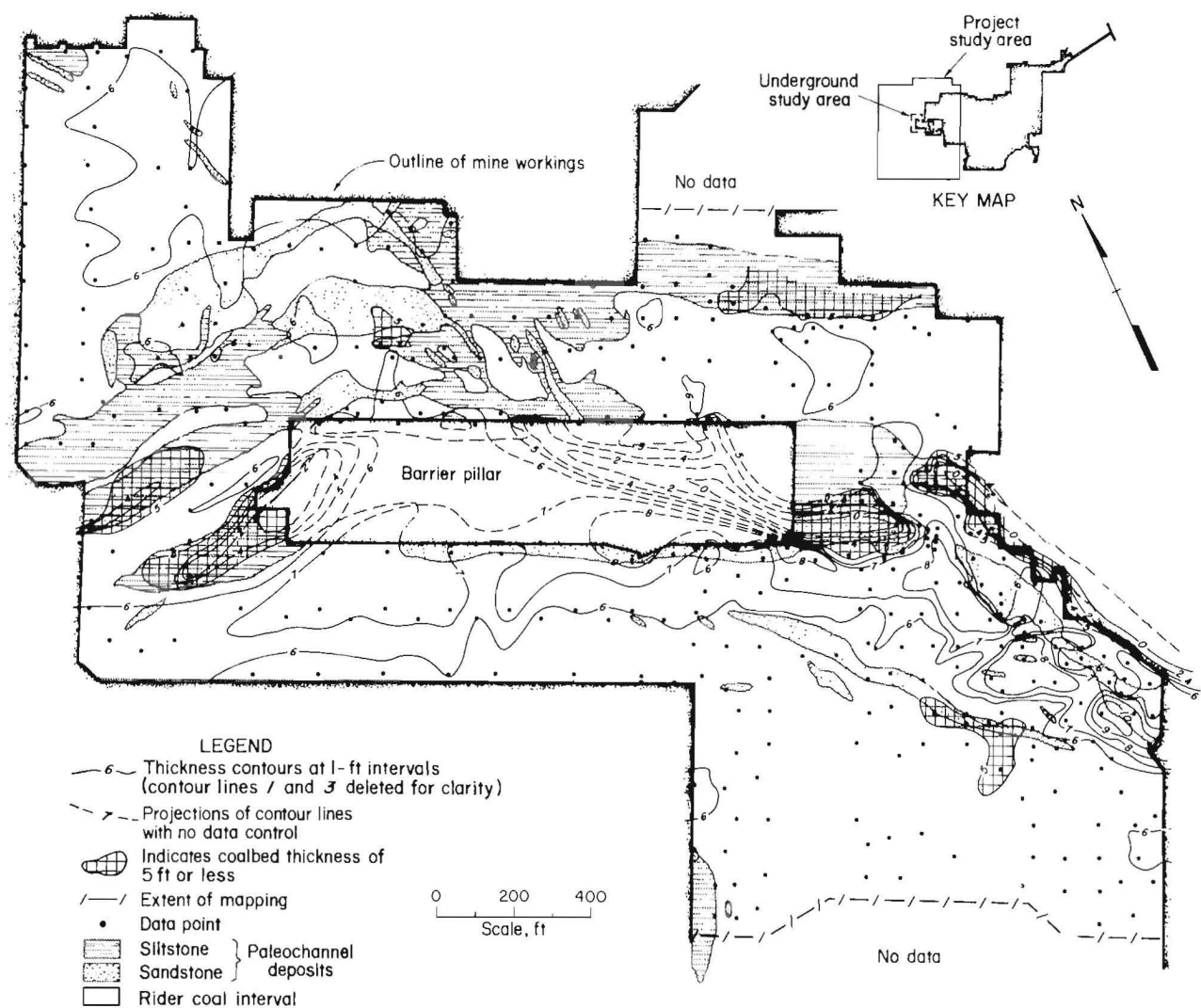


FIGURE 33.—Pittsburgh Coalbed isopach map in underground study area, illustrating areas of thin to no-coal zones.

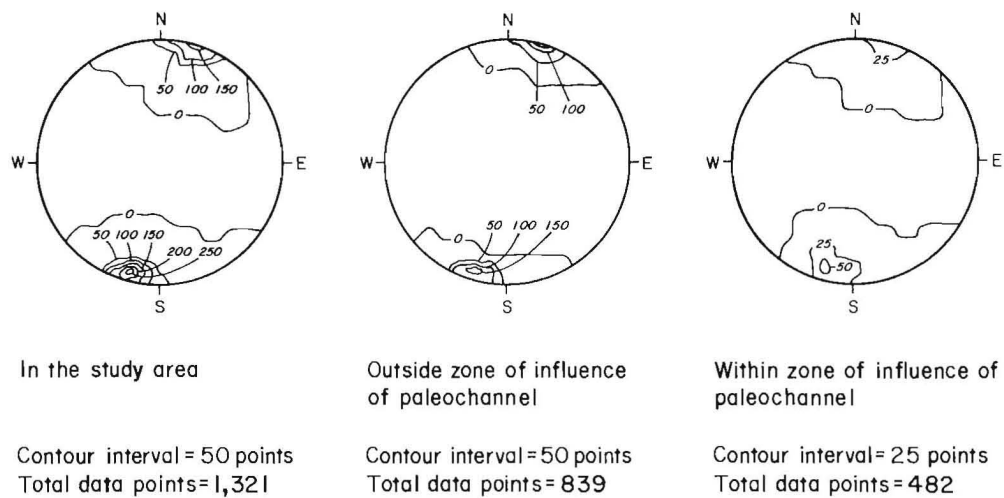


FIGURE 34.—Stereonet showing variation of face cleat strike and dip surrounding paleochannels.

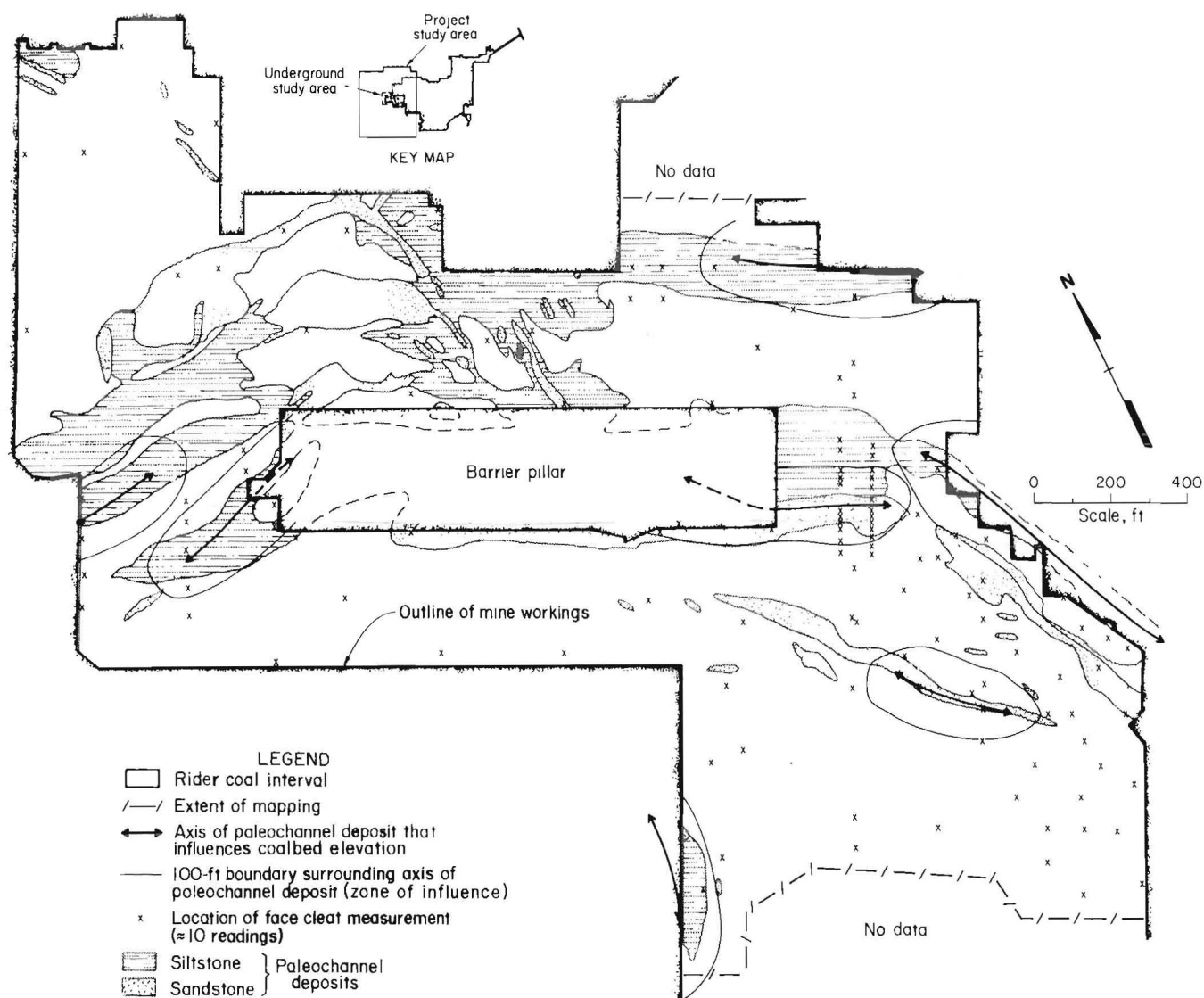


FIGURE 35.—Locations of face cleat readings in underground study area.

compounded when entries and crosscuts are oriented at acute angles to the axis of the coalbed rolls. After mining with the roll, additional floor must be cut out to level track and belt entries. This can sometimes result in rooms that are 20 ft (6.1 m) high. Furthermore, mining through hard sandstone and siltstone paleochannels can generate frictional heat and/or sparks that can cause face ignitions.

Information obtained from drill-log data combined with previous mining experience can significantly assist in planning main entries, longwall panels, and new shaft and slope locations. Larger paleochannels (similar to the one shown

in figures 22 and 23) have larger and sometimes more numerous slip planes, faults, clastic dikes, variations in coalbed elevation, and changes in coalbed thickness associated with them than do the smaller ones. Knowledge of these features and paleochannel sediments helps delineate paleochannels during mine development. Generally, larger paleochannels and their trends should be avoided when possible. Main entries should be driven away from and parallel to channel deposits to minimize contacts.

The trend of a paleochannel can be established by contacting its boundary at two or three locations along an entry. If the trend coincides with a planned

crosscut, mining of the entry should proceed beyond the paleochannel before driving the crosscut, if roof control and ventilation plans allow. This would encompass the paleochannel in a pillar.

If mining through a large paleochannel is unavoidable, the preferred orientation is at right angles to its trend to minimize the distance of exposure to the potential hazard.

CONCLUSIONS

1. Paleochannels are ancient stream channel deposits composed of sandstone and/or siltstone. Deposits have a north-west-southeast trend, which is characteristic of the Pittsburgh Sandstone distribution. Underground investigations indicate that paleochannel deposits and the adjacent rider coal interval were deposited contemporaneously.

2. Channel deposits have either eroded and/or displaced the Pittsburgh Coalbed in many places. Erosion occurred when the ancient streams cut into already deposited peat, carrying it away and then redepositing stream sediments. Coalbed displacements, which are the direct result of differential compaction, formed slip planes, faults, clay-dike faults, clastic dikes, rolls, and slump structures.

3. Mine entries beneath paleochannel deposits have less stable roof conditions than entries where the rider coal interval is present. The hazardous roof is the result of the sedimentary and structural discontinuities in and surrounding the paleochannel deposits. This study showed that classifying the rock units using only RQD values, uniaxial unconfined compressive strengths, and point-load index values does not adequately identify the true mine roof stability. Underground mapping identified numerous examples of strong rock found within unstable areas and weak rock within stable areas.

4. Properly installed tensioned bolts, in conjunction with steel mats, help to prevent spalling of loose fragmented roof that occurs in transition zones and coalbed rolls. The orientation of slips, faults, and clastic dikes related to channel deposits should be considered when selecting bolt length and angle of installation. Larger and more hazardous paleochannels may require steel sets, cribbing, or roof trusses.

5. Drill-log data, combined with underground observations, can be useful in predicting paleochannels. Contouring coalbed thickness from exploratory borehole data and knowledge of particular sediments associated with channel deposits can identify channel trends and assist in long-term projections. Recognition of common structures related to paleochannels, such as slip planes, faults, clay-dike faults, clastic dikes, coalbed rolls, changes in coalbed thickness, and slumped features can help identify the locations of paleochannels prior to encountering them during mining.

6. Main entries should be driven away from and parallel to paleochannels to minimize contacts. If paleochannels cannot be avoided, then the preferred mining orientation is at right angles to the trend of the paleochannel in order to minimize the distance of exposure to the potential hazard.

REFERENCES

1. McCabe, K. W., and W. Pascoe. Sandstone Channels: Their Influence on Roof Control in Coal Mines. MSHA (U.S. Dep. Labor), Inf. Rep. 1096, 1978, 24 pp.
2. Roen, J. B., and D. E. Farrel. Structure Contour Map of the Pittsburgh Coalbed, Southwestern Pennsylvania and Northern West Virginia. U.S. Geol. Surv. Open-File Map, 1973.
3. Berryhill, H. L., S. P. Schweinfurth, and B. H. Kent. Coal-Bearing Upper Pennsylvanian and Lower Permian Rocks, Washington Area, Pennsylvania. U.S. Geol. Surv. Proof Paper 621, 1971, 47 pp.
4. McCulloch, C. M., W. P. Diamond, B. M. Bench, and M. Duel. Selected Geologic Factors Affecting Mining of the Pittsburgh Coalbed. BuMines RI 8093, 1975, 72 pp.
5. Roen, J. B., and D. F. Kreimeyer. Preliminary Map Showing the Distribution and Thickness of Sandstone in the Lower Member of the Pittsburgh Formation, Southwestern Pennsylvania and Northern West Virginia. U.S. Geol. Surv. Misc. Field Stud. Map MF-529, 1973.
6. Kent, B. Geologic Causes and Possible Preventions of Roof Fall in Room-and-Pillar Mines. PA Geol. Surv. Inf. Circ. 75, 1974, 17 pp.
7. Deere, D. U., J. R. Dunn, and R. H. Fickies, and R. J. Proctor. Geologic Logging and Sampling of Rock Core for Engineering Purposes (Tentative). WV Geol. Surv., 1977, Appen. K, 15 pp.
8. Broch, E. J., and A. Franklin. The Point-Load Strength Test. Int. J. Rock Mech. and Min. Sci., v. 9, 1972, pp. 669-697.
9. Bauer, R. A. The Relationship of Uniaxial Compressive Strength to Point-Load and Moisture Content Indices of Highly Anisotropic Sediments of the Illinois Basin. Paper in Proceedings of Twenty-fifth Symposium on Rock Mechanics (Evanston, IL, June 1984). Soc. Min. Eng. AIME, 1984, pp. 398-405.
10. Bieniawski, Z. T. The Point-Load Test in Geotechnical Practice. Eng. Geol., v. 9, Mar. 1975, pp. 1-11.
11. Brook, N. The Use of Irregular Specimens for Rock Strengths Tests. Int. J. Rock Mech. and Min. Sci., v. 14, 1977, pp. 193-202.
12. Hassani, F. P., M. J. Scable, and B. N. Wittahu. Application of the Point Load Index Test to Strength Determination of Rock and Proposals for a New Size-Correction Chart. Paper in Proceedings of Twenty-first Symposium on Rock Mechanics (Rolla, MO, 1980). Univ. MO, 1980, pp. 543-553.
13. Read, J. R., P. N. Thorton, and W. M. Regan. A Rational Approach to the Point Load Test. Paper in Proceedings of Third Australia-New Zealand, Conference on Geomechanics (Wellington, New Zealand), v. 2, 1980, pp. 35-39.
14. Jeran, P. W., and J. H. Jansky. A Guide to Geologic Features in Coal Mines in the Northern Appalachian Coal Basin. BuMines IC 8918, 1983, 16 pp.
15. Houseknect, D. W., and A. T. Iannacchione. Anticipating Facies-Related Coal Mining Problems in Hartshorne Formation, Arkoma Basin. Am. Assoc. Pet. Geol. Bull., v. 66, No. 7, 1982, pp. 923-946.

APPENDIX.--ROCK QUALITY DESIGNATION METHOD (7)

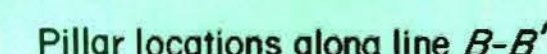
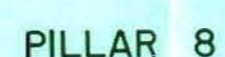
The rock quality designation (RQD) method is as follows:

Sum up the total length of core recovered in each run. Then sum up only those pieces of core that are 4 in (10 cm) in length or longer. Divide the sum of the 4 in or longer pieces by the total length of the core recovered. Multiply that quotient by 100. This final value represents a percentage of the total length of run. If the core is broken by handling or by the drilling process, the freshly broken pieces are fitted together and counted as one piece, provided that they form the requisite length of 4 in

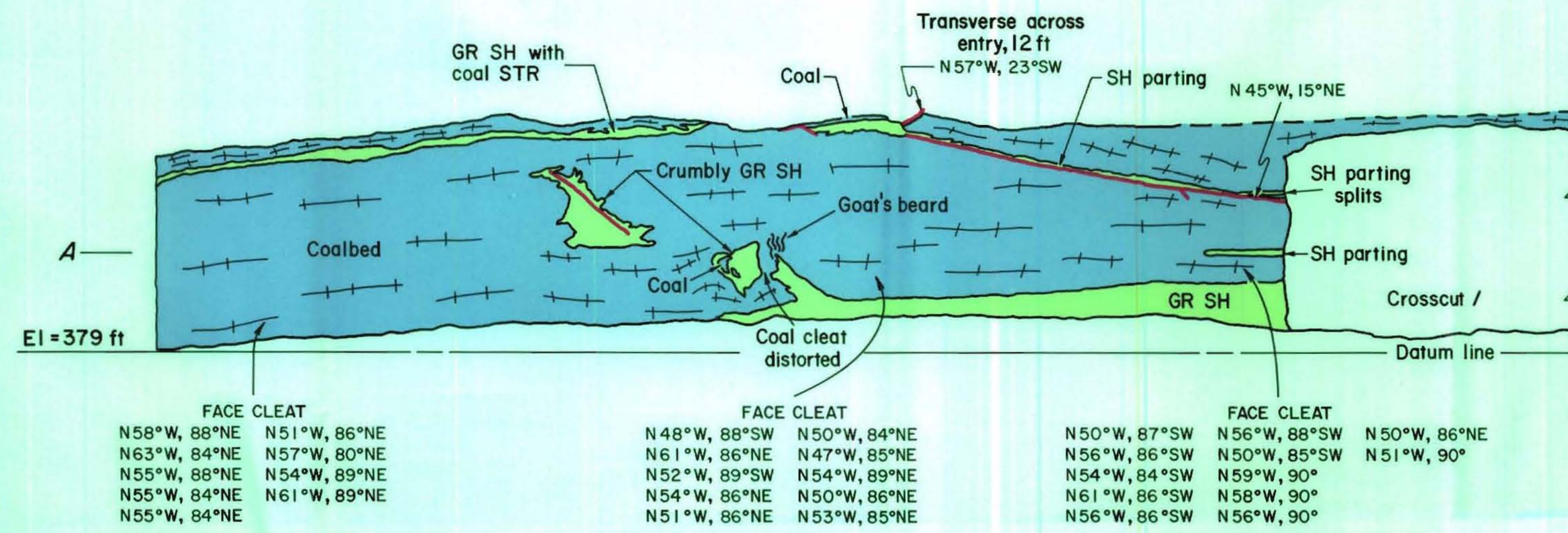
(10 cm). The relationship of RQD to rock quality is as follows:

<u>RQD, pct</u>	<u>Rock quality</u>
0 to 25.....	Very poor.
25 to 50.....	Poor.
50 to 75.....	Fair.
75 to 90.....	Good.
90 to 100.....	Excellent.

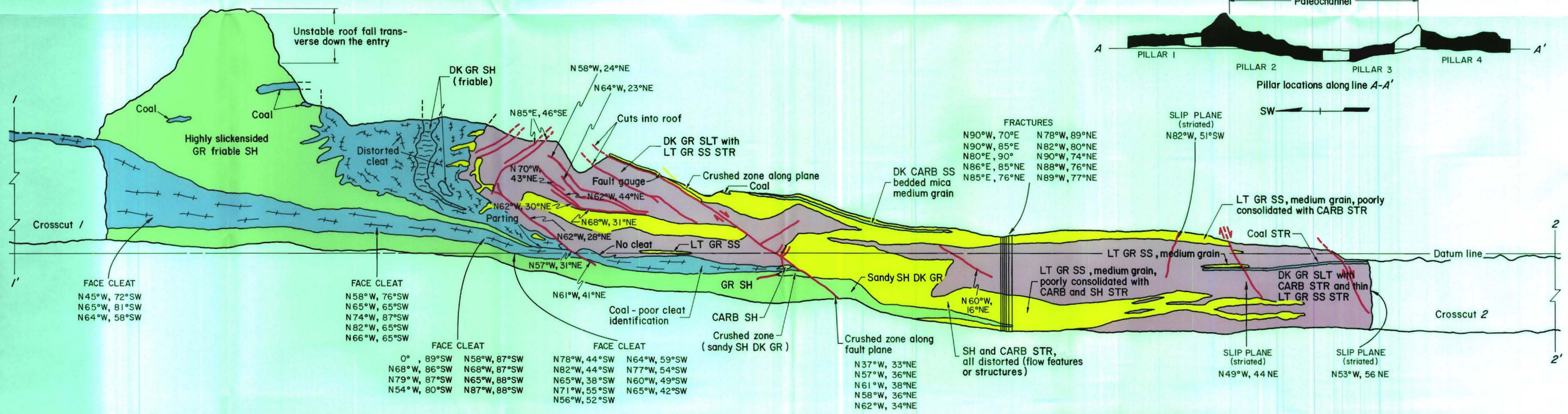
Mark the RQD percentage on the core log. This description is intended primarily for evaluating problems with tunnels or excavations in rock.



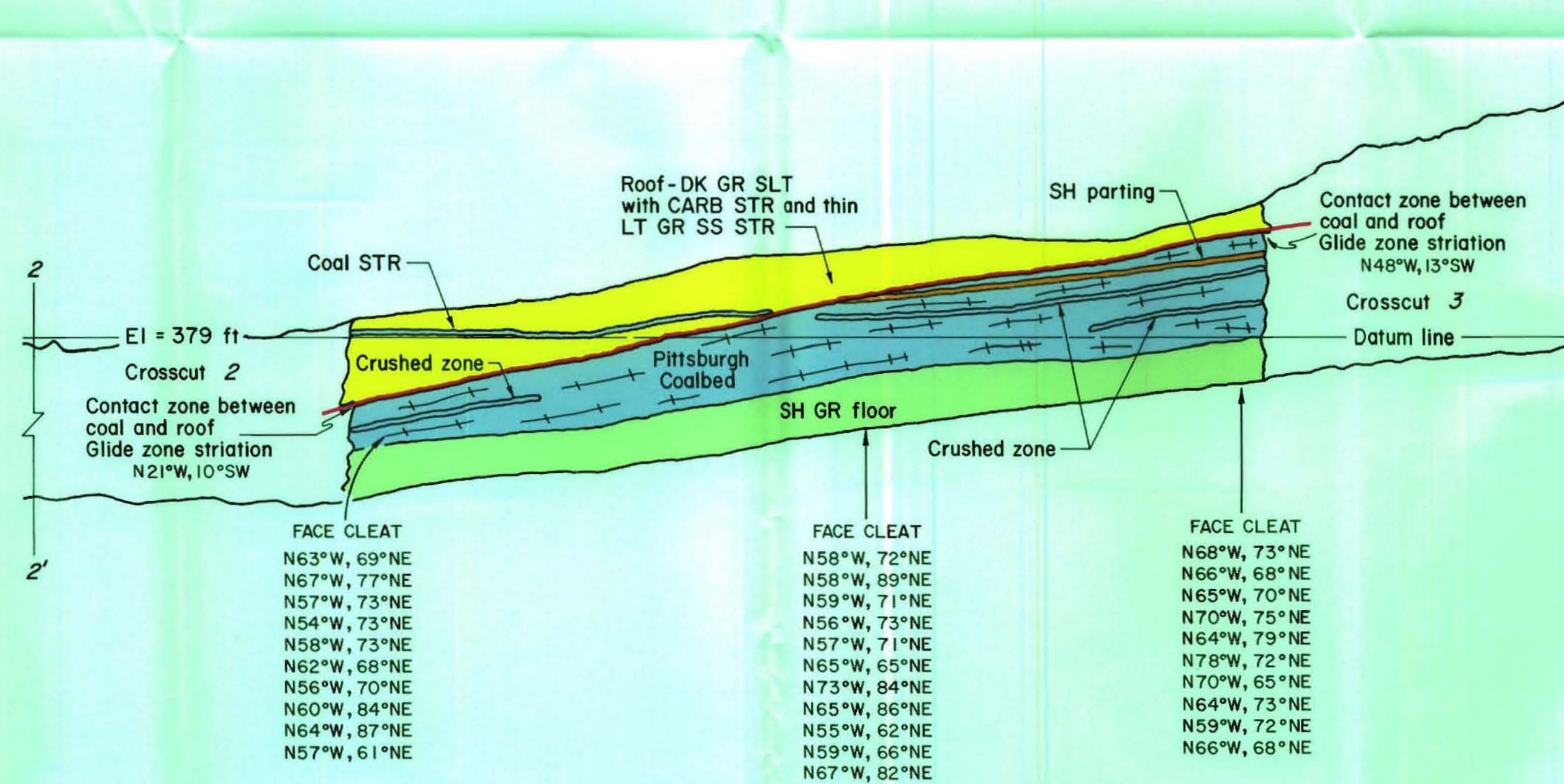
A horizontal number line labeled "Scale, ft" with tick marks at 0, 4, 8, and 12.



PILLAR 1



PILLAR 2



PILLAR 3

LEGEND

SS Sandstone DK Dark

SLT Siltstone CARB Carbonaceous

STR Streaks SH Shale

GR Gray

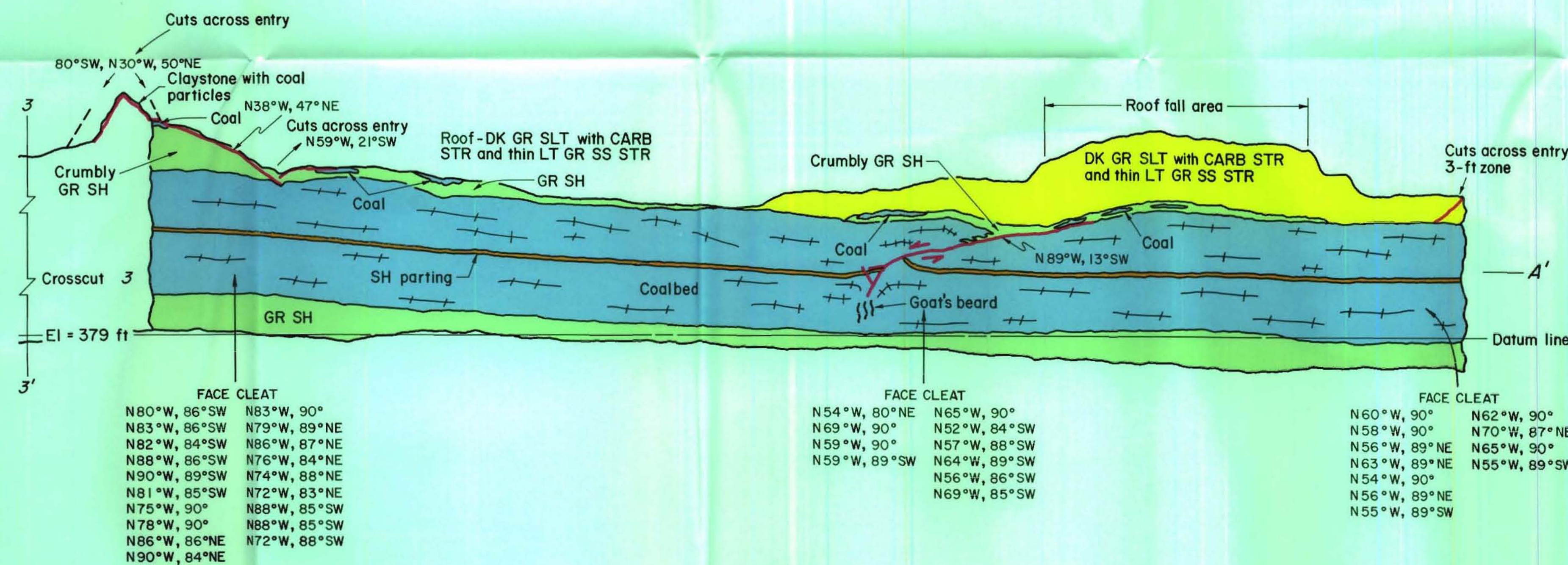
LT Light

Coal cleat

Slip plane

Scale, ft

0 4 8 12



PILLAR 4